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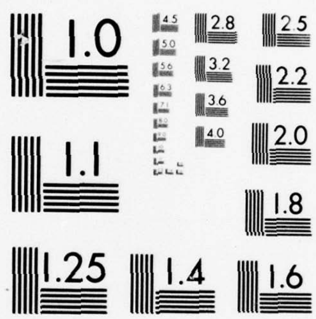

CR 78.006

CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

EFFECTIVENESS OF BUILDING INSULATION APPLICATIONS

November 1977

JOHNS-MANVILLE SALES CORPORATION
Denver, Colorado

N68305-77-C-0009

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Conduction heat transfer was measured through ten fiberglass insulated wall and ceiling test panels. Three with R-7, R-11, and R-19 (Ceiling) insulation were reference panels. Seven panels with voids, overlaps, and fixtures were compared to the reference panels. Only the void showed marked increase in conduction loss. Work was performed under Phase I of the over

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contract. Evaluation of the same panels for convection loss is being contemplated.

Contents

SUMMARY

The State of the Art of Building Insulation Thermal Performance is reviewed briefly, which shows a lack of test data on the effect of construction anomalies. A five phase Research Program is outlined, of which Phase I was funded by the current contract with the U. S. Department of the Navy, Civil Engineering Laboratory, Naval Construction Battalion Center.

This is the Final Report which covers the research conducted under the Phase I program. It includes all of the test data and other information contained in the Monthly Progress Reports issued during the course of the Phase I contract.

The Scope of the Phase I program included the investigation of the effect on the thermal performance of various construction anomalies found in residential, light-frame building. Six Wall and four Ceiling Panels were constructed and tested. Two of the Wall Panels (with R-11 and R-7 insulation) and one of the Ceiling Panels (with R-19 insulation) were constructed with no anomalies and served as a comparison standard for the panels with anomalies. The details of construction of the standard panels and the anomalies were selected from a great many possibilities as

representative of U. S. Navy residential construction during the 1950-1969 period. Photographic documentation of the construction details of the test panels has been provided.

Thermal performance was measured in the Johns-Manville Research Center Guarded Hot Box, according to the test procedure requirements of ASTM C-236. This apparatus is capable of performing thermal tests with various orientations, i.e., vertical wall panels with horizontal heat flow and horizontal ceiling panels with heat flow upward or downward. The standard panels, without anomalies, were tested at three mean temperatures, 45°F mean (winter conditions), 75°F mean, and 95°F mean (summer). The panels with anomalies were tested at 45°F mean only.

The adverse effects of anomalies were found to be more significant for walls with R-7 insulation than with R-11, because of the opportunity for convection with R-7 wall insulation. Adding an electrical box reduced the thermal resistance ("R" value) 9 percent with an R-7 wall; it had negligible effect on the R-11 wall. The R-7 wall with 4.2 percent uninsulated area, located half at the top and half at the bottom of the test area, had a 38 percent loss in "R" value. The R-11 wall, also with 4.2 percent uninsulated area, but centrally located, had a 13 percent loss in thermal resistance.

The standard ceiling panel (R-19 insulation without anomalies) had about the same thermal resistance for upward as for downward heat flow at the same mean temperature. The effect of a 4.2 percent open or uninsulated area was to reduce thermal resistance by 34 percent (increase heat loss by 50 percent). The R-19 ceiling panels with 1-inch insulation overlap and with an electrical fixture added had negligible change in thermal performance.

Calculated values of thermal performance using ASHRAE procedures for walls were found to be in good agreement with measured values. The agreement was excellent when actual thermal test data for the various components was used in the calculations rather than nominal or average values. The agreement between calculated and measured values was only fair for the ceiling panels.

The USN/CEL Naval Construction Battalion personnel are to be congratulated for their foresight in recognizing the need for detailed data on the effect of construction anomalies on thermal performance, and for their willingness to fund this research program. The results should provide valuable information for both the U. S. Navy and the broader civilian energy conservation programs. Recognition is also due the Johns-Manville Research Center Thermal Conductivity Laboratory personnel for their

willingness to persevere in their goal of reliable thermal test data in spite of many problems beyond their normal control.

BACKGROUND

The future cost and availability of energy has heightened the interest in the effectiveness of energy conservation measures. One area of particular concern is the conservation of building heating and cooling energy through installation of thermal insulation. A part of this concern is the effectiveness of these field installed building energy conservation measures, as compared with the theoretical effectiveness based on laboratory determinations.

The State of the Art has advanced to where it is possible to measure in the laboratory with great accuracy the thermal conductivity of thermal insulations and other materials used in building construction. In addition, studies reported in NBS Building Science Series 77 have shown that the laboratory measurement of the thermal conductance of composite building wall structures by means of the Calibrated Hot Box agree closely with that calculated from conductivity data using recognized ASHRAE methods. Similar agreements have been achieved with the Guarded Hot Box.

However, a major area of uncertainty in predicting the actual field thermal performance of building structures is the effect of installation and construction anomalies. It is well known that the field installation of insulation materials in particular, and building construction practices in general, can deviate substantially from the ideal as far as energy conservation is concerned. For example, estimates have indicated for a well-constructed residence that on the average, one-third of the heat loss is through doors and windows, one-third through the structure, and one-third as a result of infiltration. It is suspected that individual buildings can deviate substantially from these general averages, depending on construction deficiencies and anomalies. The actual quantitative effect of construction deficiencies on the overall thermal performance of a building has not been adequately investigated.

The scope of this work is limited to certain basic steps that will begin the process of bringing the confidence level of field testing and performance predictions up to those associated with laboratory Calibrated Hot Box testing. It is recognized that much work must be done by the insulation and construction industries, and associated testing laboratories through committees and round robin test programs. It is expected that this effort will help bring the broader industry program into focus while providing information directly applicable to improving field testing and

performance prediction capabilities, particularly as applied to Navy residential buildings.

OVERALL RESEARCH PROGRAM

The originally proposed overall Research Program has been divided into Five Phases. While this description outlines all Five Phases, only Phase I has been funded intitially.

Phase I consists of the development and testing of a series of "standard test panels" for use in a Guarded Hot Box. Each panel would incorporate an anomaly commonly found in typical residential type wall and/or ceiling construction. As proposed, these anomalies would include, but not necessarily be limited to:

A. Electrical Outlet

B. Electical Switch

C. Conduit

D. Soil Pipe

E. Incomplete Insulation Area Coverage

F. Improper Vapor Barrier Application

The dimensions of the panels would be large enough to accurately represent the particular anomaly and its surrounding wall/ceiling area. Adequate test data would be obtained so that these panels can be used as reference standards for comparison of actual to theoretical heat losses, and for further use in the

subsequent Phases of the program. The end products of this Phase will include the "standard test panels" plus a report documenting their development and test results as compared to ideal panels without anomalies.

Phase II would consist of the development of a simplified device to measure heat flow through large areas. This device should be able to accurately measure heat flows through an area in excess of four square feet, and be easy to handle and use. It should have more rapid response than a Guarded Hot Box. Upon completion of the device, it should be calibrated under steady state conditions against a variety of standard samples including wall and ceiling sections with and without anomalies. Investigation of the effects of transient conditions, and development of a method for utilization of the device to obtain a net heat flow over a fixed period of time are also part of this Phase. The end products of this Phase would include the large area heat flow measuring device, documentation of its performance, and a report on how and when it may be used.

Phase III would consist of the correlation of available field type heat flow measurement devices using the standard test panels developed in Phase I. These devices should include IR imaging, heat flux meters, and other similar devices to be defined at the time this Phase is negotiated. The end product of this Phase

would be a report delineating the areas of applicability and the reliability of the latter for each of the types of devices tested.

Phase IV would consist of an experimental investigation to determine the air infiltration through typical walls and ceilings due to construction practices, and also due to the presence of certain common anomalies. The end result would be a report relating the amount of air infiltrating through a particular construction with a given pressure differential. Details of which specific construction practices and anomalies are to be investigated would be developed after completion of Phase I.

Phase V would consist of an analysis, using the results of the first four phases, to identify which anomalies and construction practices result in the largest energy losses and to quantify these losses for typical structures. This Phase would be specifically oriented toward Navy residential construction. Practical methods for correcting deficiencies and anomalies would be developed for both new and retrofit construction. Consideration would be given to the cost effectiveness of the proposed corrective measures. The end product of this Phase would be a report documenting the work conducted in this Phase.

The above description covers the entire Research Program in order to present a complete overall view. It is anticipated,

however, that minor modifications of the latter Phases will be desirable in view of the experience of the early Phases.

PHASE I - RESEARCH SCOPE

Initial discussions with the U. S. Department of the Navy, Civil Engineering Laboratory, Naval Construction Battalion Center personnel indicated considerable effort had been expended on analyzing energy conservation means for a wide variety of Navy buildings. However, they felt that in view of the very large number of family housing buildings (Category Code 711), this area had not received sufficient attention. This Research Program was, therefore, focused on this building type.

Within the continental United States, Navy family housing units were described as typically built using similar construction methods to civilian residential building in the same geographic area. This both characterizes the details of construction used and expands the usefulness of the data developed in this program to the much larger civilian residential sector. Also, while the narrow scope of the Research Program was aimed at housing units, the same general type of construction used in housing is also found in many other types of light frame non-residential building both within and outside the Navy. Thus, the usefulness of the data developed by this Research Program is further expanded.

A typical Navy family housing unit was described as a two-story, four-unit, three bedroom townhouse built within the 20 year period 1950 to 1969.

The Research Scope is limited to the wall and ceiling portion of the building envelope. Consideration of heat loss through the doors and windows portion of the building envelope is outside the scope. Also outside the scope is the effect of moisture condensation within the insulation resulting from an inadequate or improperly installed vapor barrier. The test program will provide data on typical wall and ceiling constructions, under steady state heat flow conditions, with a simulated winter (heating season) temperature exposure.

PHASE I - RESEARCH OBJECTIVE

As described in the section entitled "Overall Research Program", the general objective of Phase I was the development and testing of a series of test panels that could be used as references for the subsequent phases of the overall program. These panels would be used in the calibration of the heat flow measuring device to be developed under Phase II. They would be needed as references in Phase III where various field type heat flux measurement devices would be correlated. In Phase IV, the investigation of air infiltration would involve comparison of field versus test panel performance

The numerical goal of test panels to be developed and tested under Phase I was set at ten. This would allow for three "Reference" Test Panels, one Ceiling and two Wall constructions. These panels would be constructed without any anomalies. The measured thermal resistance of these panels would be expected to confirm that calculated by ASHRAE methods. These "ideal" panels will serve as a reference for direct comparison of the effect of construction anomalies, to be evaluated in the remaining seven panels.

After only a cursory consideration of the number of typical construction anomalies to be characterized, it became very apparent that the test panels with anomalies should not be completely "fixed" in the sense that the three reference panels might be, but rather should readily permit future optional changes in construction. Only by providing for future ready modification of the test panels with anomalies can all of the expected interaction effects be investigated adequately under Phases II, III, and IV.

Seven test panels were to be built with anomalies, three of ceiling construction, four of wall construction. Details of construction are discussed in the next section entitled "Phase I - Test Rationale."

In addition to the construction of the three Reference Panels, and the seven panels with anomalies, Phase I includes the Guarded Hot Box testing of these ten panels according to ASTM Test Method C-236 under winter season conditions, 70°F warm surface temperature, 20°F cold surface, 45°F mean temperature. The test report to be issued was to include overall heat flux and panel conductance data. In addition, the report was to include a comparison between measured and calculated data for the reference panels, and an evaluation of the effect of the anomalies tested.

PHASE I - TEST PANEL RATIONALE

As a part of this Research Project, an assignment was placed on the Johns-Manville Corporation Information Service to determine typical civilian residential wall and ceiling construction for four major areas of the United States for the 20 year time period 1950 to 1969. Special consideration was to be given to typical insulation practice.

Various alternate constructions that might be considered "typical" for residential buildings falling within scope of this Research Project have been tabulated in Table 1 (walls) and Table 2 (ceilings). The following references, coupled with Johns-Manville experience, were used in the tabulation:

NAHB Builder Practices Study (1973) NAHB Research
  Foundation, Rockville, Maryland

Characteristics of FHA Operations Under Section 203
  for 1973, RR:250, HUD SOR-3

Characteristics of New Housing (1975),
  U. S. Department of Commerce, Bureau of Census,
  C-25-75-13

TABLE 1

TYPICAL WALL CONSTRUCTION

Interior Facing	-	1/2-inch Gypsum Board
Structure	-	2 x 4 Studs, 16-inch OC
Insulation	-	0-inch Thick without Vapor Barrier
	-	2-inch (R-7) Glass Fiber Batt with Kraft Vapor Barrier
	-	3 1/2-inch (R-11) Glass Fiber Batt with Kraft Vapor Barrier
Sheathing	-	1 x 8 T&G Boards + Sheathing Paper
	-	1/2-inch Insulation Board
	-	3/8-inch Plywood
Exterior Facing	-	4-inch Brick + 1-inch Air Space
	-	1 x 8 Wood Siding
	-	1-inch Stucco on Mesh (Without Sheathing)

<u>Alt.</u>

1/2-inch Gypsum Board, 2 x 2 Furring, 8 x 8 x 16 Concrete/Cinder Block

TABLE 2

TYPICAL CEILING CONSTRUCTION

Interior Facing	-	1/2-inch Gypsum Board
Structure	-	2 x 4 Chord Trusses, 24-inch OC
	-	2 x 6 Joists, 16-inch OC
Insulation	-	0-inch Thick without Vapor Barrier
	-	3 1/2-inch (R-11) Glass Fiber Batt with Kraft Vapor Barrier
	-	2-inch (R-7) Rock Wool Batt with Kraft Vapor Barrier
	-	6-inch (R-19) Glass Fiber Batt with Kraft Vapor Barrier
	-	4-inch Blown (Loose) Mineral Wool without Vapor Barrier

For the entire period under study, 2 by 4 studs spaced 16-inch on center were the typical frame wall construction. For Northern climates, typically 2-inches (R-7) of fiber glass batt insulation would have been installed for the early portion of the time period, 3 1/2-inches (R-11) for the latter portion. For milder climates, early construction would have had no cavity insulation, which was typically increased to 2-inches during the latter portion. At present, nearly all new construction for all areas would have 3 1/2-inch (R-11) batts installed in the wall.

Wall sheathing used initially typically was T&G boards in combination with a vapor permeable sheathing paper such as 15-pound asphalt saturated felt. Now, 1/2-inch insulating sheathing board is used commonly with some plywood sheathing, especially in lieu of corner bracing.

Ceiling construction for the early portion of the time period was typically 2 by 6 joists, 16-inch on center. Presently, nearly all ceiling construction is trusses, other than lower floors of multi-story buildings, 24-inch on center, with 2 by 4 chords. Typical insulation would have been 2 or 3 1/2-inches initially with 3 1/2 or 6-inches for later construction, with the lesser amounts used in milder climates. Currently, most construction has at least 6-inch thick ceiling insulation with much of it installed as a loose fill rather than batts.

Appendix A shows the 1954 FHA Minimum Property Requirements for insulation for the Rocky Mountain Region. This is of interest since the region covered has a wide variety of climate conditions, ranging from outside design winter temperature of -36^{O}F or less to greater than +36^{O}F. The minimum ceiling insulation acceptable is a U factor of 0.15, which is met by a fibrous insulation thickness of less than 2-inches. The minimum wall requirements are also easily met since a wall constructed of 1/2-inch by 8-inch wood siding, 1/2-inch insulation board sheathing, 2 by 4 stud space without insulation, and 1/2-inch gypsum board has a U factor of 0.22. This was satisfactory at that time for outside design temperatures down to -25^{O}F. The minimum wall and ceiling insulation requirements however, would not necessarily meet the total maximum heat loss requirement of Sec. 402-A-1.

In 1959, the "All Weather Comfort Standard", included in Appendix B, was developed primarily for electrically heated houses. It was sponsored by a number of utilities and trade associations such as:

NEMA (National Electrical Manufacturers Association),
NAHB (National Association of Home Builders),
NMWA (National Mineral Wool Association),
EEI (Edison Electric Institute), and others.

The All Weather Comfort Standard recommended heat loss values and thermal performance values, (Appendix B, Table I, "Recommended Heat Loss Values" and Table II, "Thermal Performance Values for Various Building Sections" of All Weather Comfort Standard) that are much more strict than the earlier FHA Standard. A ceiling U factor of 0.05 would require a 6 1/2-inch/R-19 fibrous insulation batt. The frame wall requirements of U = 0.07 would mean a 3 1/2-inch/R-11 batt.

About the same time (1959), NMWA also recommended insulation values for gas and oil heating and minimum comfort (Appendix B, Table A, "Recommended Installed Resistance (R) Values of Insulation" of All Weather Comfort Standard) in addition to electrical heating. As expected, the insulation recommendations for oil and gas heating were substantially less than for electrical.

The revised FHA Minimum Property Standards (1959) and (1965) increased the insulation requirements by lowering the maximum permitted total hourly heat loss (Appendix C, "Minimum Property Standards for One and Two Living Units"):

60 BTU/hour/square foot floor area (1954)

50 BTU/hour/square foot floor area (1959)/(1965)

40 BTU/hour/square foot floor area (1959)/(1965)

(Electric Heating)

The above documentation confirms the validity of the typical insulation practice described in Table 1 "Typical Wall Construction" and Table 2 "Typical Ceiling Construction".

Construction anomalies likely to have a significant affect on wall and ceiling thermal performance have been tabulated in Tables 3 and 4. The above are to be considered anomalies in the sense that they are not accounted for in the usual ASHRAE calculations, which make an allowance only for stud or joist through conduction. The tabulations in Tables 3 and 4 are not to be considered anomalies in the sense that they are atypical, for they are in fact, very real parts of residential construction.

TABLE 3

COMMON WALL CONSTRUCTION ANOMALIES

Sheathing/Sheath Paper	- Discontinuities
Electric Wiring	- Parallel to Studs
	- Perpendicular to Studs
	- Wall Box with Receptacle/Switch
Plumbing	- Supply Parallel Studs
	- Supply Perpendicular Studs
	- DWV Parallel Studs
	- DWV Perpendicular Studs
	- Above with Gypsum Board Penetrations
Framing	- Less than 16-inch Stud Space
	- Corner Brace
	- Blocking
	- Fire Stop
Insulation Installation	- Poor Fit Caused by Above
	- Poor Fit Top/Bottom/Sides
	- Omitted Areas
	- Incomplete Vapor Barrier

TABLE 4

COMMON CEILING CONSTRUCTION ANOMALIES

Electric Wiring	- Parallel to Joists
	- Perpendicular to Joists
	- Electric Box with Fixture
Framing	- Joist Lap
	- Greater than, Less than Standard Joist Space
Insulation Installation	- Poor Fit Caused by Above
	- Batt Over/Under Lap
	- Batt Compression
	- Loose Fill Non-Uniform Cover
	- Loose Fill Settling

To develop a series of test panels that would characterize both wall and ceiling constructions, and consider "ideal" and typical deviations within a limitation of ten units, required considerable engineering judgment based on testing experience in this field. By eliminating variations of exterior wall facing from consideration, the testing program could be simplified. Thus, the wall test panels would consist of sheathing, 2 by 4 framing with the possibility of various insulation anomalies, and gypsum board interior facing. The decision to exclude exterior wall facing can be justified on the basis that the thermal resistance of the exterior facing is small compared with the overall thermal resistance of an insulated residential wall. Much data already exists on the thermal resistance of a wide variety of exterior facings, and results of the current wall panel study can be readily converted to consider the effect of the exterior facing. The proposed test panel schedule, which was subsequently accepted by USN/CEL personnel, without modification, is shown in Table 5.

TABLE 5

CONSTRUCTION TEST PANEL DETAIL SCHEDULE

PANEL NO.	TYPE	INTERIOR FACING	FRAMING	INSULATION	SHEATHING	ANOMALY
1 (Reference)	Wall (Vertical Orientation)	1/2-inch Gypsum Board	2 x 4 16-inch On Center	3½-inch (R-11) Batt with Kraft Vapor Barrier	1/2-inch Insulation Board	None
2	Wall (Vertical Orientation)	1/2-inch Gypsum Board	2 x 4 16-inch On Center	3½-inch (R-11) Batt with Kraft Vapor Barrier	1/2-inch Insulation Board	2-inch Open Area (Without Insulation)
3	Wall (Vertical Orientation)	1/2-inch Gypsum Board	2 x 4 16-inch On Center	3½-inch (R-11) Batt with Kraft Vapor Barrier	1/2-inch Insulation Board	Electric Box, Wiring & Receptacle
4 (Reference)	Wall (Vertical Orientation)	1/2-inch Gypsum Board	2 x 4 16-inch On Center	2½- inch (R-7) Batt with Kraft Vapor Barrier	1/2-inch Insulation Board	None
5	Wall (Vertical Orientation)	1/2-inch Gypsum Board	2 x 4 16-inch On Center	2½- inch (R-7) Batt with Kraft Vapor Barrier	1/2-inch Insulation Board	Convection Path Top & Bottom (Two 1-inch open areas
6	Wall (Vertical Orientation)	1/2-inch Gypsum Board	2 x 4 16-inch On Center	2½- inch (R-7) Batt with Kraft Vapor Barrier	1/2-inch Insulation Board	Electric Box, Wiring & Receptacle
7 (Reference)	Ceiling (Horizontal Orientation)	1/2-inch Gypsum Board	2 x 6 16-inch On Center	6-inch (R-19) Batt with Kraft Vapor Barrier	None	None
8	Ceiling (Horizontal Orientation)	1/2-inch Gypsum Board	2 x 6 16-inch On Center	6-inch (R-19) Batt with Kraft Vapor Barrier	None	2-inch Open (Without Insulation)
9	Ceiling (Horizontal Orientation)	1/2-inch Gypsum Board	2 x 6 16-inch On Center	6-inch (R-19) Batt with Kraft Vapor Barrier	None	1-inch Overlap of Insulation
10	Ceiling (Horizontal Orientation)	1/2-inch Gypsum Board	2 x 6 16-inch On Center	6-inch (R-19) Batt with Kraft Vapor Barrier	None	Electric Box with Wiring & Ceiling Fixture

The Reference Test Panels No. 1, No. 4, and No. 7 would be constructed without anomalies and would serve as the comparison base for the balance of the panels. The decision to include a Reference Wall Panel with 2 1/2-inch (R-7) batt in addition to 3 1/2-inch (R-11) batt was based on the high frequency of occurrance of 2-inch wall batt during the time period of interest and the expected very poor performance of this construction when mis-installed to permit ready convection paths (Test Panel No. 5).

The choice of 2 by 6 joists, 16-inch on center, versus 2 by 4 truss chords, 24-inch on center, for ceiling structure was pretty even. The decision to select the joist construction was based on potential discontinuities when 6-inch (R-19) batts were installed between 2 by 4 (3 1/2-inch net height) framing members.

The anomalies selected were selected for their prevalence and expected detrimental effect on measured thermal performance.

General construction details of the wall and ceiling test panels are shown in Figures 1 and 2.

FIGURE 1

STANDARD WALL TEST PANELS

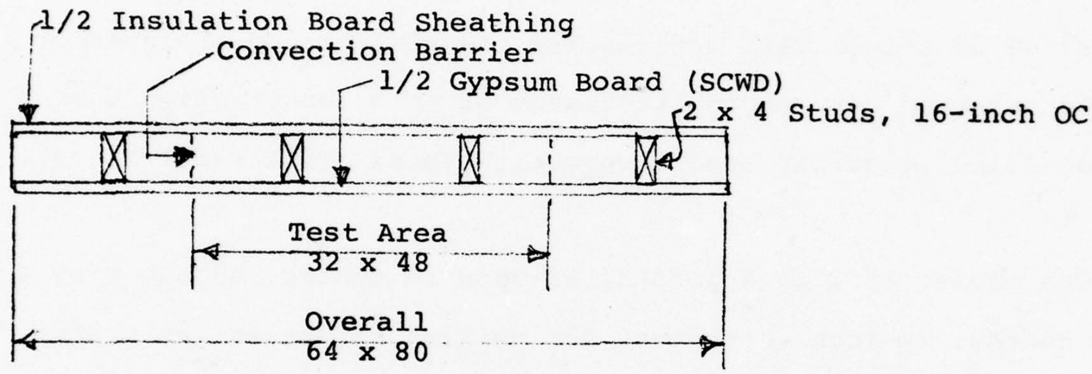
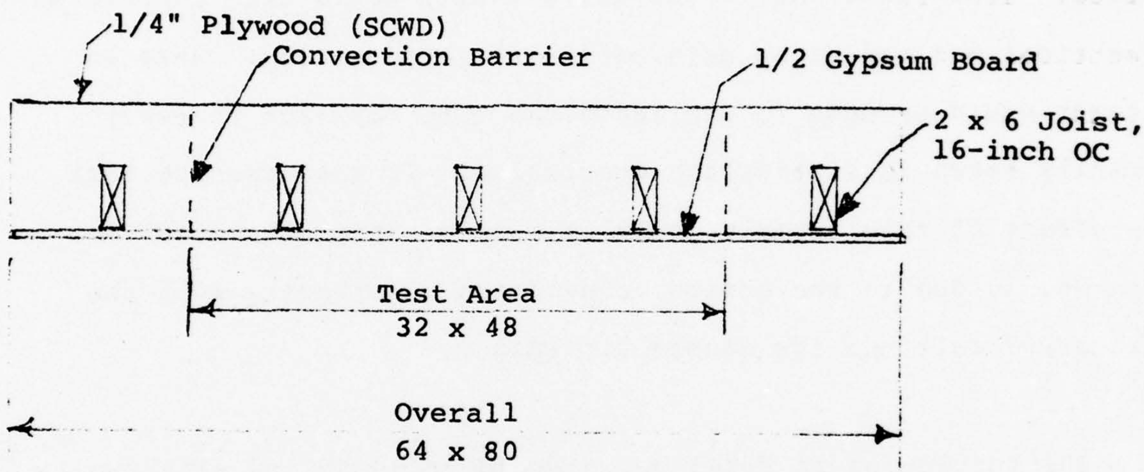


FIGURE 2

STANDARD CEILING TEST PANELS



The details of construction of the panels with anomalies were to be identical to that of Reference Panels, except for the anomalies incorporated. Test Panels No. 2 (wall) and No. 8 (ceiling) would have a single 2-inch wide open space or gap in the insulation in the test area. This was to simulate a careless installation in which the stud or ceiling space is incompletely filled. Test Panels No. 3 and No. 6 (wall) would each contain an electrical box and receptacle, and associated wiring. Here an attempt would be made to duplicate the care (or lack thereof) normally taken in fitting the insulation. It was expected that the effect of this anomaly would be much greater with Panel No. 6 than No. 3, due to the greater convection opportunity with the 2-inch/R-7 batt and its double air space.

The insulation in Panel No. 5 would be installed with two 1-inch open areas, one each at the top and the bottom of the stud cavity. By the direct communication thus afforded between warm side and cold side air spaces, convection is expected to be much higher than in the corresponding reference Panel No. 4.

In Panel No. 9 (ceiling), the batt would be intentionally overlapped 1-inch, as commonly occurs during careless installation. Since the overlap might allow convection paths directly from the gypsum board ceiling surface, this anomaly was expected to be of primary importance during winter (heat flow upward) conditions. Test Panel No. 10 (ceiling) is similar to

No. 3 and No. 6 (wall) except for the substitution of a ceiling electric box and fixture for a wall box and receptacle.

All panels were to be tested under winter conditions (45°F mean, 70°F interior face, 20°F exterior face); wall panels with heat flow horizontal, ceiling panels with heat flow upward. Since the Reference Test Panels (No. 1, No. 4, and No. 7) will be used both as a basis of comparison for the other panels with anomalies and for comparison with previous test results including ASHRAE calculations, it was considered desirable to have test data on their performance as a function of mean temperature. In addition to the winter condition, two other test conditions were proposed for these panels at 75°F mean temperature (100°F/50°F) and 95°F mean temperature (120°F/70°F). The latter would simulate summer conditions; 75°F mean temperature is the common temperature for evaluating building insulation. Since the ceiling panel could exhibit different thermal performance with heat flow up, than heat flow down, Panel No. 7 would be tested under both conditions at 75°F mean, and with heat flow down at 95°F mean.

The proposed increase in the scope of the contract to include additional mean temperature data on the three reference panels without any increase in the contract amount was also accepted by USN/CEL personnel, with the understanding that this would delay the scheduled completion date.

TEST PANEL CONSTRUCTION

The test panels were constructed in accordance with the schedule in Table 5. All panels were assembled in such a fashion to permit subsequent verification of the internal construction, or changing of the insulation through ready removal of one of the faces. In all cases, the highest quality workmanship expected in residential housing was used, except where anomalies were intentionally incorporated.

Extensive use was made of photographic documentation during the construction of the test panels. This included black and white photographs included in Appendix D of this report, and 2 x 2 color slides taken at the same time. Five duplicate sets of the color slides have been delivered to USN/CEL personnel. The same identification numbers apply to both series of pictures.

The first three test panels, to be used as references, were constructed first as per sketches, Figure 3 and 4. These included:

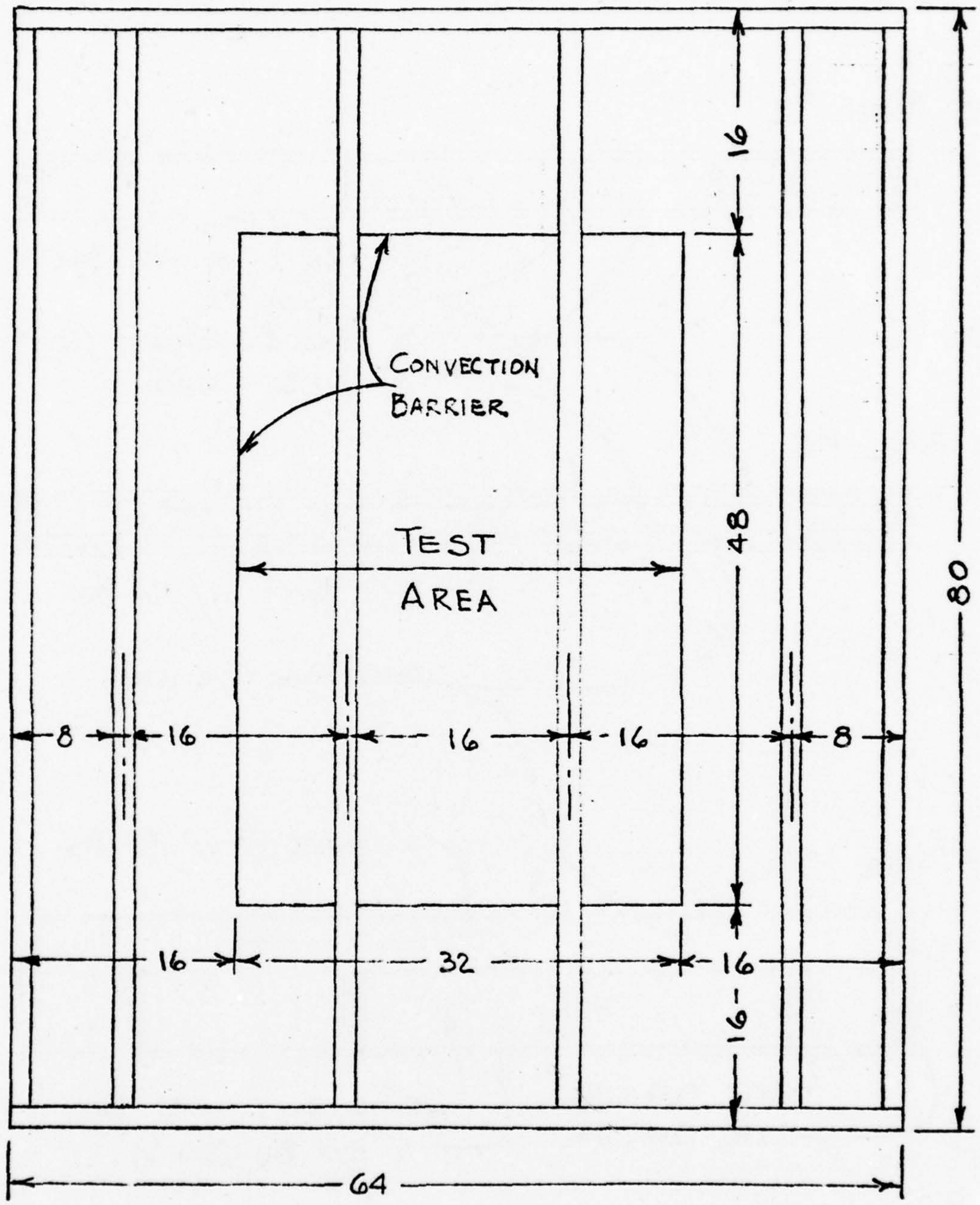
Panel No. 1 - Wall - R-11 Insulation (no anomalies)

Panel No. 4 - Wall - R-7 Insulation (no anomalies)

Panel No. 7 - Ceiling - R-19 Insulation (no anomalies)

Some construction details were common to all panels. The sheet facing materials, 48-inch wide, were installed parallel to the long or 80-inch direction (Appendix D, Picture No. 1, Picture No. 5). Joints occurred over the outer studs or joists, i.e., no joints in the facing occurred over the 32-inch wide center test area. To protect the rather fragile edges of the gypsum board and the insulating board faces, metal "J" molding was installed (Picture No. 1, Picture No. 7).

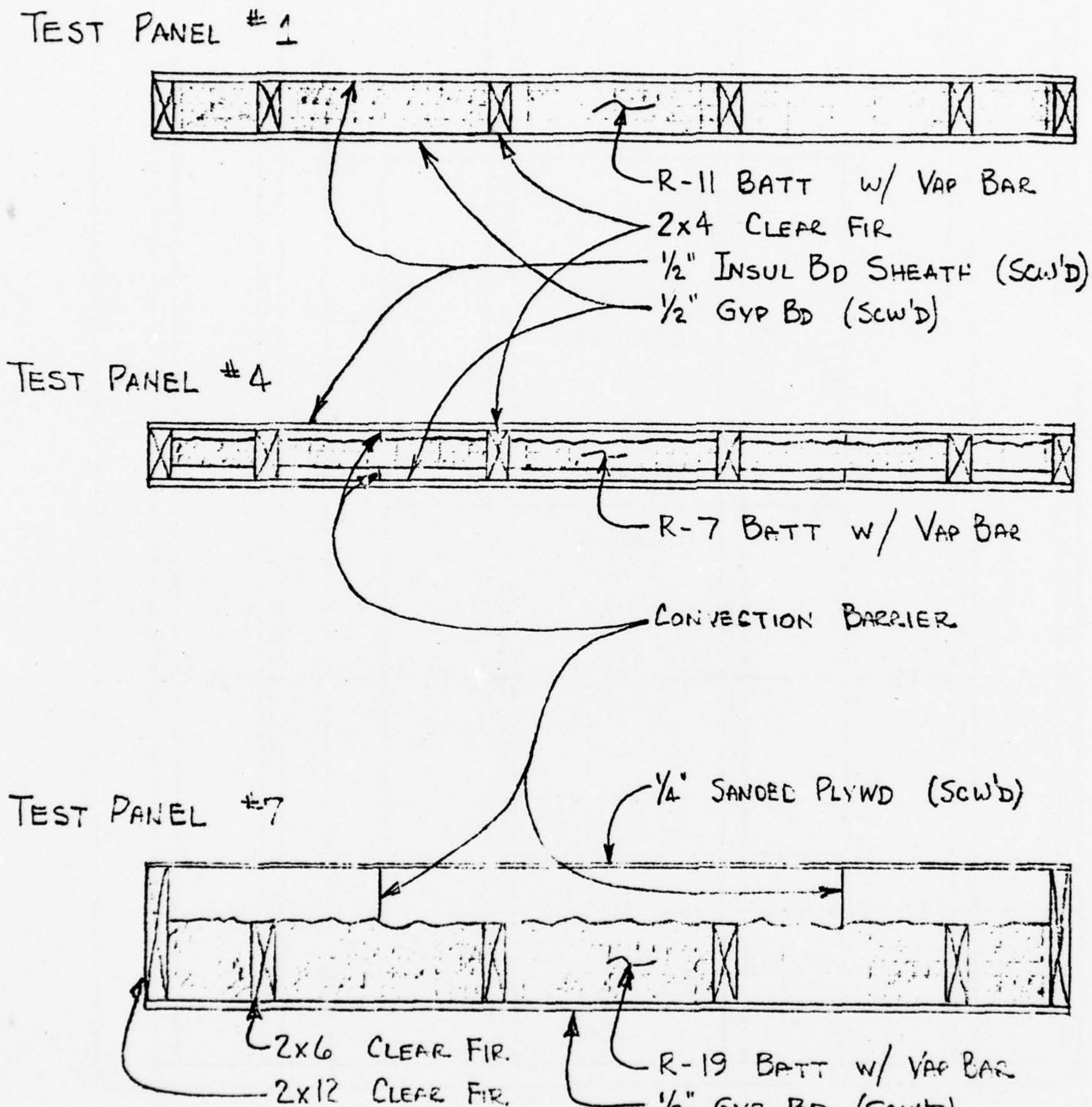
FIGURE 3



INTERNAL CONSTRUCTION
ALL TEST PANELS

SCALE 1IN = 1FT

FIGURE 4



CONSTRUCTION DETAILS

SCALE 1 IN = 1 FT

The insulation used was selected to be in the 0.6 to 0.7 pcf range, which was typical for glass fiber batts produced during the 1950 to 1969 period. Since R-7 batts are no longer commonly manufactured, it was necessary to cut down R-11 batts, using a horizontal band saw. Sufficient R-7 insulation was prepared at one time to complete the construction of all R-7 wall panels.

Since the R-11 batt installed in Test Panel No. 1 completely fills the wall cavity, the insulation thickness was the depth of the cavity or 3.5-inch. The R-7 batt installed in the Wall Test Panel No. 4, and the R-19 batt installed in Ceiling Test Panel No. 7 were not of full depth. For these panels, it was necessary to install lacing strings to locate the batts in the proper position (Picture No. 10, No. 15, and No. 17). Lacing strings were not installed on the inside wall cavity of Test Panel No. 4 since they would interfere with the stapling flange, and the vapor barrier paper serves a similar function (Picture No. 10).

The R-11 batts used in Test Panel No. 1 and the R-7 batts prepared for Test Panel No. 4 had the vapor barrier attached to the batt (Picture No. 3, No. 4, and No. 10). In the case of the R-19 batts used in Test Panel No. 7, it was felt that a better installation job could be accomplished with separate batts and vapor barrier (Picture No. 15, No. 16, and No. 17).

Again, with the batt filling the cavity in Test Panel No. 1, no convection barrier was required here (Picture No. 2). With open cavities, both Test Panel No. 4 and No. 7 required the installation of barriers. These were fabricated of 1/2-inch thick insulating board sheathing (Picture No. 9, No. 12, and No. 14). Barriers were installed in both inside (Picture No. 11) and outside cavities (Picture No. 8) of Panel No. 4 and in the top side cavity of Panel No. 7 (Picture No. 13). These barriers were cemented to the facing, or between the studs as appropriate (Picture No. 11). In each case, the barriers continued the location of the 32 by 48 test area through the test panel. The barriers were designed to compress the insulation slightly, in order to provide a reasonably tight perimeter seal.

Each panel was provided with a lifting hook (Picture No. 4) for handling, and permanently identified with the test panel number and the United States Navy/CEL contract number (Picture No. 7).

At the time the test panels were constructed, samples of the insulation used were taken. Before testing the panels in the Guarded Hot Box, the steady state thermal transmission properties of the insulation samples was determined in a 36-inch Heat Flow Meter Apparatus meeting the requirements of ASTM C-518. At 75^{o}F mean temperature and 3.50-inches thickness, the measured thermal resistance of the R-11 insulation used was 11.2 BTU^{-1}/hr/sq ft/^{o}F

at a tested density of 0.71 lb/cu ft. At the same mean temperature and 2.50-inches thickness, the measured thermal resistance of the R-7 insulation used was 7.3 BTU^{-1}/hr/sq ft/^{O}F at a tested density of 0.53 lb/cu ft. While the R-7 insulation was cut off from the same batch as the R-11 insulation, its density was somewhat less. This is due to the R-7 insulation, as installed, being freer to expand to its full thickness (and lower density), whereas the R-11 insulation, as installed, was confined by the stud depth of approximately 3 1/2-inch.

All test panels with anomalies were constructed similar to the reference panels without anomalies. Test Panel No. 2 (R-11 wall insulation with 2-inch uninsulated area) was constructed similar to Test Panel No. 1 (R-11 wall insulation without anomalies). The difference was the omission of the R-11 insulation and vapor barrier for a 2-inch wide area. This open area was oriented horizontally, extended the full width of the test area, and was located at the mid point of the test panel. The uninsulated portion was 2/48 or 4.2 percent of the insulation area. Masking tape was used to repair minor rips in the vapor barrier as required.

Test Panel No. 5 (R-7 wall insulation with two 1-inch uninsulated areas) was likewise constructed similar to Test Panel No. 4 (R-7 wall insulation without anomalies). The difference was the omission of the R-7 insulation and vapor barrier for two

1-inch areas. Each area was also oriented horizontally and extended the full width of the test area. One open area was located at the top of the test area, the other at the bottom. The open or uninsulated areas provided direct connection between the air spaces on either face of the R-7 insulation, and thus permitted a ready path for an air thermo-siphon or convection loop. The total uninsulated portion in Test Panel No. 5 was 4.2 percent of the insulation area, the same as Test Panel No. 2.

Photographs taken during the construction of Test Panel No. 2, (Picture 24) and Test Panel No. 5 (Picture 25) are included in Appendix D.

Test Panel No. 3 (R-11 wall insulation with electrical receptacle) was constructed similar to Test Panel No. 1 (R-11 wall insulation without anomalies). Also, Test Panel No. 6 (R-7 wall insulation with electrical receptacle) was constructed similar to Test Panel No. 4 (R-7 wall insulation without anomalies).

The electrical receptacles in Test Panels No. 3 and No. 6 were installed in a similar fashion. A 2 by 3 by 2 1/2-inch deep metal electrical box with clamps for non-metallic cable and an integral side bracket was centrally located 40-inches from the top edge of the panel (center of the test area) and mounted on the side of the stud forming the center stud space. The box was wired with 14-2 non-metallic sheathed cable (Romex) with separate ground

conductor. To simulate typical use conditions, the wiring was extended horizontally through the center of the studs at a point 18-inches below the box. Each cable was stapled to the side of the adjacent stud at a point about 4-inch below the box and also just before the turn to traverse horizontally. The wiring was completed by installing a duplex receptacle and a plastic cover plate.

The insulation was installed in a manner similar to that used in the previous wall panels. The R-11 insulation was jointed at the horzontal wiring. This represents good installation practice as it permits maximum conformity of the insulation to wiring irregularities. Unfortunately, this practice is not always universally followed. In the case of the R-7 insulation, the material was installed on the gypsum board side of the horizontal wiring, which resulted in a slight local compression of the insulation. For both installations, the insulation and vapor barrier were cut out to the approximate dimensions of the electrical box. Photographs taken during the construction of the Test Panel No. 3 (Picture 26) and Test Panel No. 6 (Picture 27) are included in Appendix D. Picture 28 shows the completed Test Panel No. 6; Test Panel No. 3 would be similar.

Test Panel No. 8 (R-19 ceiling insulation with 2-inch wide uninsulated area), Test Panel No. 9 (R-19 ceiling insulation with 1-inch overlap) and Test Panel No. 10 (R-19 ceiling insulation

with ceiling electrical fixture) were constructed similar to Test Panel No. 7 (R-19 ceiling insulation without anomalies).

The 2-inch wide uninsulated area in Test Panel No. 8 was located at the midpoint, similar to the 2-inch uninsulated area in Test Panel No. 3 (R-11 wall insulation with 2-inch uninsulated area). In both cases the uninsulated area extended the full width of the test area or 32-inches. The uninsulated portion was 2/48 or 4.2 percent of the insulation in the test area. As with Test Panel No. 3, the vapor barrier was omitted in the uninsulated area. Details of construction are shown in Picture 29.

Test Panel No. 9 was designed to demonstrate the effect of a batt improperly installed in that it overlapped the adjacent batt by 1-inch. The batt, therefore, was not in contact with the ceiling gypsum board for a length of about 12-inches. The location of the overlapped batt was central to the test area, and occurred only in the center joist space. See Picture 30 for details.

Test Panel No. 10 was designed to demonstrate the effect of a ceiling light fixture. A 4-inch octagonal metal box with clamps for non-metallic cable was fastened to the side of the ceiling joist in the central joist space. The box was centrally located lengthwise in the test area. The box was wired with 14-2

non-metallic sheathed cable (Romex) with separate ground conductor. The wiring was extended diagonally on both sides of the box, with wiring on top of the joists. Staples fastened the cable to the side of the joist within 4-inches of the box and on top of each joist. See Picture 31 for details. The installation was completed by intalling a modest priced 2-lamp ceiling fixture found typically in residential applications (see Picture 32).

In the process of insulating Panels No. 8 through 10, it became apparent that it would be difficult to maintain the nominal 6 to 6 1/2-inch thickness of R-19 ceiling insulation with a high degree of consistency between panels using the system of locating strings employed originally in insulating the Reference Ceiling Panel No. 7, (shown in Picture 17). By only attaching the locating strings at the panel edges, the natural resilience of the glass fiber batts caused a degree of bowing, with the greatest uncertainty of thickness occurring in the center or over the test area. To solve this problem, it was decided to fasten the locating strings at each 2 x 6 ceiling joist. This resulted in some compression of the batt which reduced its effective R-value. However, this effect could be calculated for, and with the improved thickness control, the comparison of Panels No. 8, No. 9, and No. 10 with Panel No. 7 would be enhanced. Panel No. 7 was subsequently reworked so that its top surface was similar to that of Panels 8 through 10 shown in Pictures 29-31. Picture 17,

showing the original construction of the inside Panel No. 7, is therefore no longer valid.

During the test program, the thermal resistance for Test Panel No. 7 with heat flow down, was found to be unexpectedly low. This was believed to be caused by the lack of structural strength of the support for the plywood top surface of this panel. The weight of the test area Hot Box caused the plywood to deflect, making the surface non-planar, and adversely affecting the seal between the test area and the quard area of the Hot Box Assembly.

The top surface structure of Test Panel No. 7 was rebuilt by adding 2 by 4 supports, both cross-wise and length-wise, outside of the insulation board convection barrier. In addition, damaged portions of the convection barrier were repaired by cutting out the crushed areas, and cementing in pieces of similar material.

No similar modifications were made to Test Panels No. 8, No. 9 and No. 10, since these were tested only in the heat flow up position, with the test area Hot Box below the test panel.

TEST PROCEDURE

The thermal performance of each panel was determined by the test procedure of ASTM C-236, Standard Test Method for Thermal Conductance and Transmittance of Built-up Sections by Means of the Guarded Hot Box. Figure 5, taken from ASTM C-236, shows the essential details of the Guarded Hot Box Test Apparatus.

Details of the interior construction of the Johns-Manville Research Center Guarded Hot Box Apparatus are shown in Picture No. 18 (warm side metering and guard boxes), No. 19 (cold box, cooling coils and circulation fan behind baffle), and No. 20 (warm side boxes left, cold box behind test panel). The thermocouples used to measure the warm surface temperature are shown in Picture No. 21. Similar thermocouples were installed on the reverse or cold surface. The completed installation, ready for test and the control panel are shown in Picture Nos. 22 and 23 respectively.

FIGURE 5

C 236

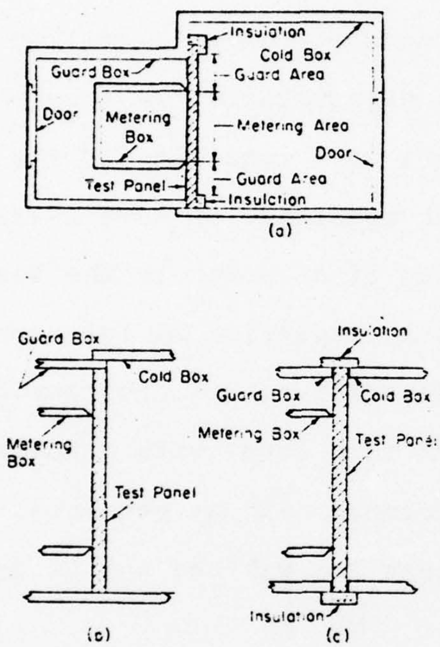


FIG. 1 General Arrangements of Test Box, Guard Box, Test Panel, and Cold Box

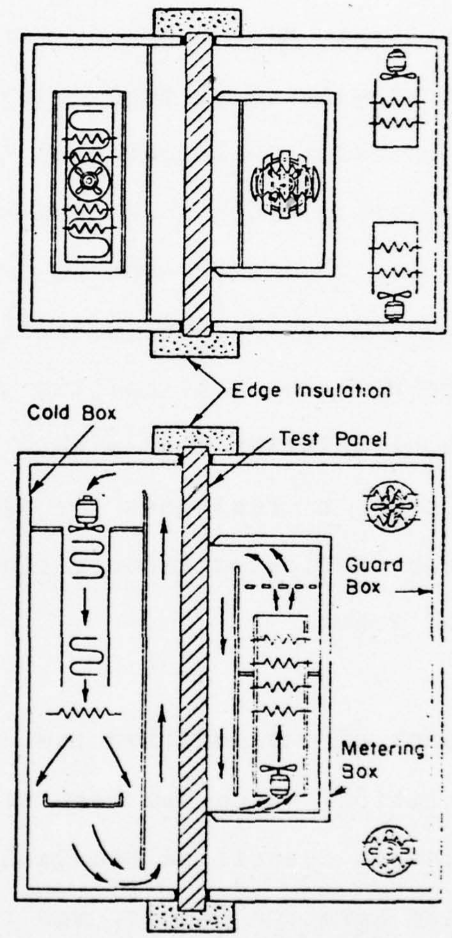


FIG. 2 Arrangement of Equipment During the Test.

test periods criteria required by ASTM C-236 was not nearly always strict enough. Especially with high thermal resistance panels, test data was obtained which met this requirement but differed substantially from the true thermal equilibrium data.

The relatively high thermal resistance of the R-19 ceiling panels compared with usual test panels, necessitated two changes in the test procedure. Longer test times were required for the thermal equilibrium, much more than that specified in ASTM C-236. In addition, the automatic control system of AC power to the test area used previously, was not sufficiently sensitive at low power. The procedure with the R-19 ceiling panels was to use constant AC power to the circulation fans within the test area, with manually adjusted DC power to resistors for additional heat as required. The total heat dissipated through the test are was the sum of the AC and the DC power.

As a check of the modified test procedure, a standard sample of roof insulation, which had been tested previously at the National Research Council of Canada Laboratories and at the Johns-Manville Research Center, was installed in the Guarded Hot Box Test Apparatus used for conducting the current USN/CEL test. The results of this test on the standard sample, agreed closely with both previous test results. This validated the combined AC and DC test area power procedure.

The raw data taken from the Guarded Hot Box at each point was fed into a programable calculator. These results were then compiled. A typical compilation (for Panel No. 6 at 45^{o}F mean) is shown in Table 6. All data for Phase I of this project are recorded in Johns-Manville Research Center Notebooks 4742 and 4794, which were used exclusively for this purpose.

A detail of ASTM Standard Test Method C-236 deserves amplification at this point. Section 5.5.1 describes the measurement of surface temperature. It calls for thermocouples to be located judiciously with respect to structural members in the panel. When testing wall panels, it has been our practice in the past to locate some thermocouples over studs with the balance of the thermocouples over the between-the-stud area. The average surface temperature was than determined as the area weighted average between over stud and insulation surface temperatures. This practice was continued when testing wall panels with anomalies, the average surface temperature in this case including also an area weighting for the surface temperature over the anomaly.

Another section of ASTM C-236 requires the taking of data over a minimum of 8-hours, consisting of two consecutive 4-hour periods, with a maximum difference of 1 percent in the measured average conductance values over the two 4-hour periods. The test reported here were continued at least a second day for a second 8-hour period. Values reported are the averages of the four 4-hour periods. In most cases, the results of the second 8-hour period duplicated those of the earlier period. In a few cases, the mean temperature shifted slightly for the second day. Here the difference in measured conductance for the second day results was that expected due to the change in mean temperature. In general, the less than 1 percent difference over successive 4-hour

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GUARDED HOT BOX THERMAL TRANSMISSION PROPERTIES CALCULATIONS

SAMPLE NO. 7825-6 MEAN TEMPERATURE 45°F

MEETS ASTM C-236 WITHIN 1%

Test Point	1	2	3	4	5	6
Avg. Temp. Summary (°F)						
Hot Side Air	72.03	71.98	72.00	72.05		
Sample Hot Surf.	67.47	67.47	67.51	67.51		
Sample Cold Surf.	20.15	20.23	20.04	20.43		
Cold Side Air	18.67	18.93	18.73	19.18		
Balance (mv)	-0.007	-0.001	0.000	0.001		
Watt-Hour Data (Rev)						
Current	69.42	206.11	339.03	478.47		
Previous	0.00	69.42	206.11	339.03		
Difference	69.42	136.69	132.92	139.44		
Time Data (min)						
Current	30.00	89.00	146.50	207.00		
Previous	0.00	30.00	89.00	146.50		
Difference	30.00	59.00	57.50	60.50		
Heat Flows Btu/(hr·ft^2)						
Total to Meter Area	5.1704	5.1766	5.1652	5.1498		
Balance Correction	-0.0172	-0.0025	0.0000	0.0028		
Net Heat Flow	5.1532	5.1742	5.1652	5.1527		
Air to Air Results						
Temp.	53.37	53.05	53.27	52.67		
C Btu/(hr·ft^2·°F)	0.096562	0.097534	0.096968	0.097465		
R (hr·ft^2·°F)/Btu	10.356	10.253	10.313	10.260		
Mean Temp.	45.35	45.46	45.37	45.62		
Surface to Surface Results						
Temp.	47.32	47.24	47.46	47.08		
C Btu/(hr·ft^2·°F)	0.108899	0.109523	0.108821	0.109440		
R (hr·ft^2·°F)	9.183	9.130	9.189	9.137		
Mean Temp.	43.81	43.85	43.78	43.97		
Hot Air Film						
Temp.	4.56	4.51	4.49	4.54		
C Btu/(hr·ft^2·°F)	1.130	1.147	1.150	1.134		
R (hr·ft^2·°F)/Btu	0.885	0.872	0.870	0.882		
Mean Temp.	69.75	69.73	69.75	69.78		
Cold Air Film						
Temp.	1.48	1.30	1.71	1.24		
C Btu/(hr·ft^2·°F)	3.466	3.967	3.944	4.150		
R (hr·ft^2·°F)/Btu	0.288	0.251	0.254	0.241		
Mean Temp.	19.41	19.58	19.39	19.90		

Summary for 8 Readings

Max "C"	0.109527
Min "C"	0.108821
% Diff	-0.642
Avg "C"	0.109171
Std Deviation	0.000352

Summary Pg 22

Summary of Readings 1-4

Avg of Readings 1-4

Avg of Readings 5-8

% Diff (to meet ASTM should be less tha

ANALYSIS

The test results of Panel No. 1 (R-11 wall without anomalies) are tabulated in Table 7 for the three mean temperatures of 45°F, 75°F, and 95°F. Similar test results for Panel No. 4 (R-7 wall without anomalies) are tabulated in Table 8. The above results are plotted in Figure 6.

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TABLE 7

TEST RESULTS - PANEL NO. 1
(R-11 WALL WITHOUT ANOMALIES)

	Test 1-1	Test 1-2	Test 1-3
TEMPERATURE, ^{o}F			
Hot Air	70.2	100.5	123.4
Hot Surface	68.3	98.3	121.1
Cold Surface	22.0	50.1	71.3
Cold Air	20.3	48.3	69.5
Surface/Surface, mean	45.2	74.2	96.2
Surface/Surface, ΔT	46.3	48.2	49.8
RESISTANCE $BTU^{-1}/hr/sq\ ft/^{o}F$			
Hot Air Film	0.5	0.5	0.5
Surface/Surface	11.9	10.9	10.0
Cold Air Film	0.4	0.4	0.4
Total	12.8	11.8	10.9
CALCULATED RESISTANCE (at $75^{o}F$ mean) $BTU^{-1}/hr/sq\ ft/F^{o}$			
Surface/Surface		11.3*	
CONDUCTANCE $BTU/hr/sq\ ft/^{o}F$			
Surface/Surface	0.084	0.092	0.100
Air/Air	0.078	0.085	0.092

* corrected, see text.

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TABLE 8

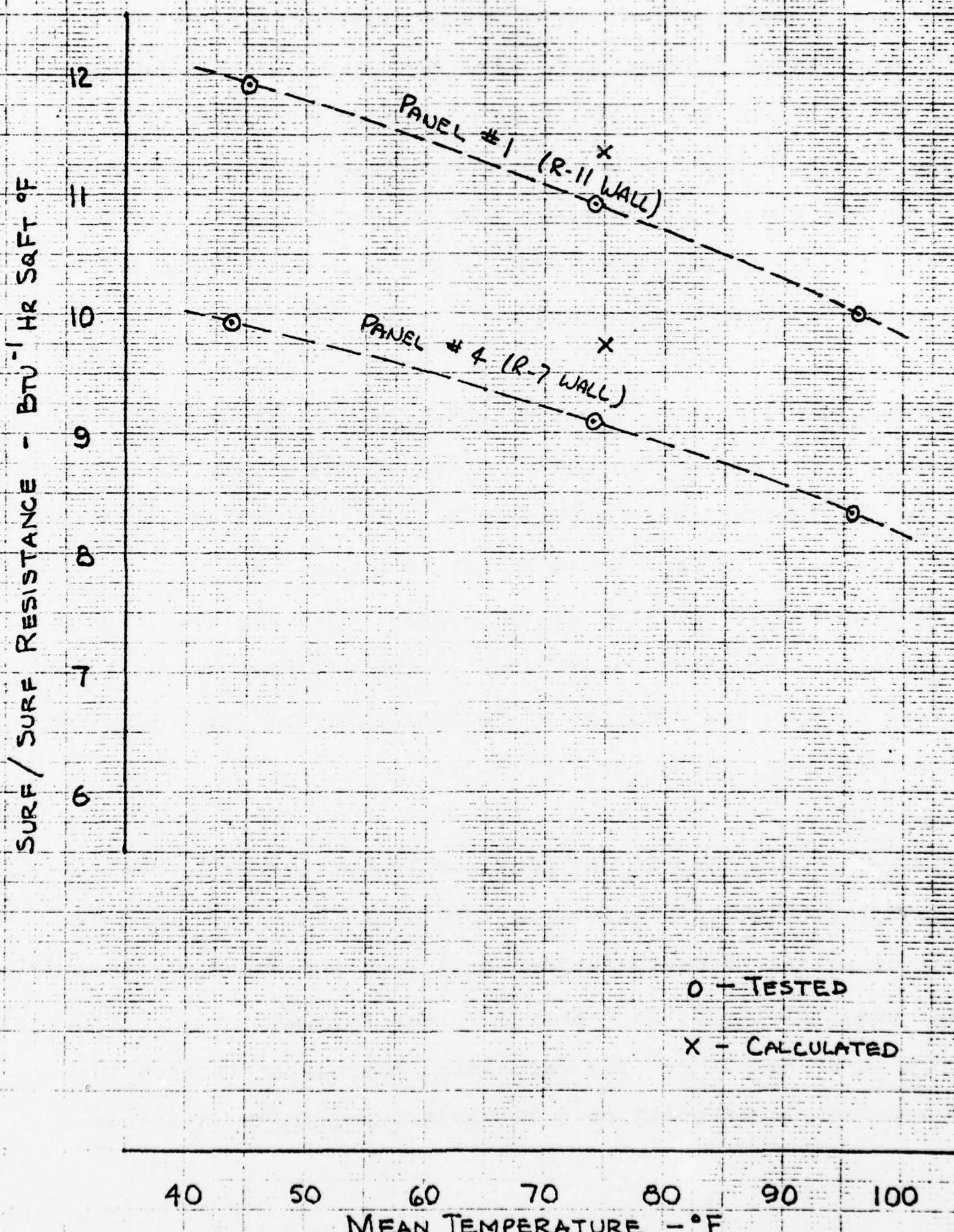
TEST RESULTS - PANEL NO. 4
(R-7 WALL WITHOUT ANOMALIES)

	Test 4-1	Test 4-2	Test 4-3
TEMPERATURE, °F			
Hot Air	69.6	101.8	122.7
Hot Surface	66.0	97.8	118.8
Cold Surface	21.6	50.3	72.4
Cold Air	19.6	47.8	70.2
Surface/Surface, mean	43.8	74.0	95.6
Surface/Surface, ΔT	44.4	47.5	46.4
RESISTANCE BTU^{-1}/hr/sq ft/°F			
Hot Air Film	0.8	0.8	0.7
Surface/Surface	9.9	9.1	8.3
Cold Air Film	0.5	0.5	0.4
Total - Air/Air	11.2	10.4	9.4
CALCULATED RESISTANCE (at 75°F mean) BTU^{-1}/hr/sq ft/°F			
Surface/Surface		9.7*	
CONDUCTANCE BTU/hr/sq ft/°F			
Surface/Surface	0.101	0.110	0.120
Air/Air	0.089	0.096	0.106

* corrected, see text.

Figure 6

Test Results



The expected surface to surface thermal resistance of the R-11 and the R-7 Panels at 75^{o}F mean temperature was calculated using the procedures and accepted values outlined in the 1972 ASHRAE Handbook of Fundamentals. The average or typical accepted values for the resistance of the sheathing board, gypsum board, air space, and wood studs were taken from this reference. The exception was the actual measured thermal resistance of the batt insulation. The calculated thermal resistance was 0.6 to 0.9 "R" units higher than that measured.

Samples of 1/2-inch sheathing and 1/2-inch gypsum board similar to that used in the construction of these test panels were obtained and thermal resistance determined. The average measured thermal resistance of the sheathing at 75^{o}F mean was 1.02 BTU^{-1}/hr/sq ft/^{o}F; that of the gypsum board was 0.41, for a total of 1.43. Accepted values used in the original calculations were from ASHRAE 1972 Handbook of Fundamentals, and were 1.32 and 0.45 respectively, for a total of 1.77.

Clear fir was used in the construction of the test panels. Two thermal conductivity test specimens were fabricated by edge laminating pieces of construction material. The average measured thermal conductivity at 75^{o}F mean of clear fir was 0.81 BTU/in/hr/sq ft/^{o}F. The calculated thermal resistance then for 3 1/2-inch studs would be 4.32 BTU^{-1}/hr/sq ft/^{o}F, which is

practically identical with the ASHRAE Handbook of Fundamentals value of 4.35 used in previous calculations.

For both panels, the calculated surface to surface resistance values were still slightly higher than actually measured after corrections for the actual rather than nominal resistance of the gypsum board and the sheathing were made. There are a number of possible explanations for this difference. Some earlier work at the Johns-Manville Research Center showed that there was a small, but significant, reduction in the measured wall thermal resistance due to the fasteners (nails or screws) used to attach the sheathing board and the gypsum board faces to the studs. Also, the resistance of the two air spaces for the R-7 insulation was the value taken from ASHRAE for narrow (3/4-inch) air spaces, whereas the actual air space on the warm side of the wall averaged 0.60-inches, that on the cold side 0.37-inches.

All of the above factors would tend to make the calculated surface to surface resistance somewhat higher than the actual, as was observed. In view of this, the agreement between measured and calculated values is considered excellent.

It is customary to rate the thermal performance of building materials at 75°F mean temperature. This represents something of a compromise between winter conditions and summer conditions. As shown in Figure 6, the winter performance of a wall should be

about 10 percent better than designed, that for summer about 10 percent poorer. This is not serious in view of the many other much grosser assumptions that go into the prediction of the thermal performance of a given wall, the amount of air infiltration expected for example.

The test results of the effect of uninsulated portions of wall panels are tabulated in Table 9. Panel No. 2 (R-11 wall insulation) has a 2-inch wide uninsulated area, centrally located. Panel No. 5 (R-7 wall insulation) has two 1-inch wide uninsulated areas located at the top and the bottom of the test areas.

While the uninsulated portion of the Test Panel No. 2 was only 2-inches out of 48-inches, or 4.2 percent of the area between the studs, the measured decrease in surface to surface thermal resistance was 13 percent. This checks with calculations for the expected change in overall thermal resistance for Panel No. 2, which was also 13 percent.

TABLE 9

TEST RESULTS - WALL PANELS
WITH UNINSULATED AREAS

	Test 2-1	Test 1-1	Test 5-1	Test 4-1
CONSTRUCTION				
Panel	Wall	Wall	Wall	Wall
Insulation	R-11	R-11	R-7	R-7
Anomaly	1-2" space (central)	None	2-1" spaces (top & bottom)	None
TEMPERATURE - ^{o}F				
Hot Air	75.6	70.2	76.2	69.6
Hot Surface	71.7	68.3	70.4	66.0
Cold Surface	20.2	22.0	20.7	21.6
Cold Air	18.4	20.3	18.0	19.6
Surface/Surface, mean	46.0	45.2	45.6	43.8
Surface/Surface, ΔT	51.5	46.3	49.7	44.4
RESISTANCE $BTU^{-1}/hr/sq\ ft/^{o}F$				
Hot Air Film	0.8	0.5	0.7	0.8
Surface/Surface	10.3	11.9	6.2	9.9
Cold Air Film	0.4	0.4	0.3	0.5
Total - Air/Air	11.5	12.8	7.2	11.2
CONDUCTANCE $BTU/hr/sq\ ft/^{o}F$				
Surface/Surface	0.097	0.084	0.161	0.101
Air/Air	0.087	0.078	0.139	0.089
COMPARISON				
Effect of Anomaly on Surface/Surface "R"	-13%		-38%	
Calculated Effect of Anomaly on Surface/Surface "R" (at 75^{o}F mean)	-13%			

The decrease in measured thermal resistance for Test Panel No. 5 compared with similarly insulated Panel No. 4 was 38 percent. This is equivalent to a 61 percent increase in heat loss. While the total area of the non-insulated portion for Panel No. 5 was no larger than with Panel No. 2, in the case of No. 5, it was distributed equally at the top and bottom of the test area cavity. Since the R-7 insulation used in Panel No. 5 had an air space on both the warm and cold surfaces, the addition of the uninsulated areas top and bottom completed the potential convection path. That the closed loop convection path was effective as a heat transfer device was demonstrated by the marked decrease in thermal resistance. Due to unknowns associated with the convection mode of heat transfer, no calculations were attempted for the expected thermal resistance of Panel No. 5.

The marked reduction in thermal resistance of wall panels when convection is permitted was also found in a qualitative sense by Teitsma and Peavy. Their recently published [1]paper concerned research at NBS on a mobile home which had 2 by 4 stud walls with R-7 glass fiber batt insulation. They stated "as currently installed, a portion of the R-7 insulation in the walls is made ineffective by the passage of cold air through the insulated cavity, siphoning air around the insulation. ...It appears that full, thick, properly installed insulation substantially reduces or eliminates air movement in insulated cavities".

The overall conclusions of Teitsma and Peavy have been substantiated by this research. Their quantitative estimate of a 9 percent reduction of overall wall resistance due to movement of cold air within the wall would appear to be much too conservative.

Thermal data on the testing of Panels No. 3 (R-11 wall insulation with electrical receptacle) and No. 6 (R-7 wall insulation with electrical receptacle) are reported in Table 10 along with similar data on Panels No. 1 (R-11 wall insulation without anomalies) and No. 4 (R-7 wall insulation without anomalies) at the same mean temperature for comparison.

The thermal resistance values for the two R-11 wall panels show substantially no difference. In fact, the thermal resistance of the panel with the electrical box was slightly better than the panel without. This small difference is within the expected limits of experimental variation. On the other hand, the addition of an electrical receptacle to the R-7 insulated wall panel markedly reduced the thermal resistance, by about 9 percent.

The above observations are consistent with the previously observed results on Panels No. 2 and No. 5 i.e., with a wall insulation which completely fills the wall cavity (R-11 batt), the effect of an anomaly is small and predictable. When the wall insulation does not fill the cavity (R-7 batt), the air spaces on either side of the insulation permit convection heat flow to

operate when an anomaly is present, thus materially reducing the measured thermal resistance from that under ideal conditions (Panel No. 4).

TABLE 10

TEST RESULTS - WALL PANELS
WITH ELECTRICAL BOXES

	Test 3-1	Test 1-1	Test 6-1	Test 4-1
CONSTRUCTION				
Panel	Wall	Wall	Wall	Wall
Insulation	R-11	R-11	R-7	R-7
Anomaly	elec. box	none	elec. box	none
TEMPERATURE - ^{o}F				
Hot Air	73.9	70.2	72.1	69.6
Hot Surface	70.3	68.3	67.6	66.0
Cold Surface	19.3	22.0	21.6	21.6
Cold Air	18.1	20.3	19.0	19.6
Surface/Surface, mean	44.8	45.2	44.6	43.8
Surface/Surface, ΔT	51.0	46.3	46.0	44.4
RESISTANCE $BTU^{-1}/hr/sq\ ft/^{o}F$				
Hot Air Film	0.8	0.5	0.9	0.8
Surface/Surface	12.1	11.9	9.0	9.9
Cold Air Film	0.3	0.4	0.5	0.5
Total	13.2	12.8	10.4	11.2
CONDUCTANCE $BTU/hr/sq\ ft/^{o}F$				
Surface/Surface	0.083	0.084	0.111	0.101
Air/Air	0.076	0.078	0.096	0.089
COMPARISON				
Effect of Anomaly on Surface/Surface "R"	nil		-9%	

More problems were experienced in obtaining satisfactory test data from Test Panel No. 7 (R-19 ceiling insulation without anomalies) than with all the other panels combined. The original insulation used to construct Test Panel No. 7 was not within specification, and it was replaced with new material similar to that used in the wall panels, which Johns-Manville identifies as type "H" insulation. The thermal conductivity of the replacement material was determined at three thicknesses, at 75°F mean temperature, using the heat meter apparatus and test procedure described in ASTM C-518. The same material was used for the three tests, the changes in thickness affecting the density in an inverse relationship. The results of these tests agreed very closely with a regression analysis of many thermal conductivity tests on type "H" insulation at the Johns-Manville Research Center. The analysis includes factors for density and thickness variations.

In the case of Wall Panels No. 1, No. 2, and No. 3, R-11 insulation was used, which would more than fill the wall cavity, without compression. The insulation thickness in this case was identically equal to the width of the wall cavity, which inturn was determined uniquely by the width of the studs. Where the insulation was of less thickness than that of the cavity, some means of establishing the insulation thickness was necessary. As originally constructed, Test Panel No. 7 had containment or location cords on the top surface which traversed the entire width

of the test panel, as shown in Picture No. 17. The first tests conducted on Panel No. 7, Tests 7-1, 7-2, and 7-3, were with the panel constructed in this fashion. The measured average thickness of the insulation was 6.41-inches, and the calculated resistance for the insulation at this thickness and density was 20.2 $BTU^{-1}/hr/sq\ ft/^{o}F$.

The above system of insulation thickness control was not considered completely satisfactory, due to the resilience of this product causing subsequent uncertainty of thickness. While increased thickness will reduce density and thereby increase thermal conductivity slightly (reduce thermal resistivity), this effect is small compared with the direct increase in thermal resistance with thickness.

As described in the section on TEST PANEL CONSTRUCTION, Ceiling Test Panels No. 8, No. 9, and No. 10 were insulated with material from the same lot as that used for reinsulating Panel No. 7, but with defining cords fastened to the top of each joist as shown in Picture No. 29. Test Panel No. 7 was subsequently reworked in a similar fashion, with the result that the average insulation thickness after rework was 5.66-inches. The calculated R at this thickness and density was 18.7 $BTU^{-1}/hr/sq\ ft/^{o}F$. Tests 7-4 and following on Panel No. 7 were with this reduced thickness insulation.

The test results on Panel No. 7 with (R-18.7 insulation) are shown in Table 11. The tests were conducted with heat flow up at 45°F and 75°F mean temperatures, simulating winter conditions, and heat flow down at 75°F and 95°F simulating summer conditions. Also included in Table 11 are calculated values of overall surface to surface resistance at 75°F mean based on ASHRAE procedures with allowance for joists, and previously determined data.

The calculated thermal resistance values for heat flow up and heat flow down at the same mean temperature were practically the same. While the resistance of an air space with heat flow down is higher than with heat flow up, this effect was balanced by the higher conductance at the higher mean temperature when the heat flow was reversed.

The agreement between measured and calculated values is fair with heat flow up, and somewhat poorer with heat flow down. In dismantling Test Panel No. 7, it was found that the quarter-inch plywood top surface did not have sufficient strength to support the weight of the inner or test area assembly of the Guarded Hot Box when the apparatus was assembled for heat flow down. This had allowed the test area box to drop and made the seal between the test area and surrounding guard area imperfect. The data reported in Table 11 for heat flow down, is that obtained after the top surface of Test Panel No. 7 was strengthened.

TABLE 11

TEST RESULTS - PANEL NO. 7
(R-19 CEILING WITHOUT ANOMALIES)

	Test 7-4	Test 7-5	Test 7-9*	Test 7-10*
CONSTRUCTION				
Panel	Ceiling			
Insulation	R-19			
Anomaly	none			
HEAT FLOW	up	up	down	down
TEMPERATURE - $^{\circ}F$				
Hot Air	72.6	100.0	101.7	121.4
Hot Surface	70.9	98.4	98.8	118.1
Cold Surface	20.7	50.0	49.4	71.3
Cold Air	17.8	47.5	48.4	70.2
Surface/Surface, mean	45.8	74.2	74.1	94.7
Surface/Surface, ΔT	50.2	48.5	49.4	46.8
RESISTANCE BTU^{-1}/hr/sq ft/$^{\circ}$F				
Hot Air Film	0.6	0.6	1.0	1.0
Surface/Surface	19.1	16.5	16.2	13.6
Cold Air Film	1.1	0.8	0.3	0.3
Total	20.9	17.9	17.5	14.9
CALCULATED RESISTANCE (at 75°F mean) BTU^{-1}/hr/sq ft/$^{\circ}$F				
Surface/Surface		17.8	17.9	
CONDUCTANCE BTU/hr/sq ft/$^{\circ}$F				
Surface/Surface	0.052	0.061	0.062	0.073
Air/Air	0.048	0.056	0.057	0.067

* Test conducted after top surface of test panel reinforced, see text.

Table 12 contains test results on Ceiling Test Panels No. 8 (R-19 insulation with 2-inch uninsulated area), No. 9 (R-19 insulation with 1-inch overlap of insulation), and No. 10 (R-19 insulation with ceiling electrical fixture). These tests were conducted at 45°F mean with heat flow in the upward direction. This configuration simulates winter conditions.

TABLE 12

TEST RESULTS - CEILING PANELS WITH ANOMALIES

	Test 8-1	Test 9-1	Test 10-1	Test 7-4
CONSTRUCTION				
Panel	ceiling	ceiling	ceiling	ceiling
Insulation	R-19	R-19	R-19	R-19
Anomaly	1-2" space	1" overlap	electric box	none
HEAT FLOW	up	up	up	up
TEMPERATURE - $^{\circ}$F				
Hot Air	72.3	71.2	71.1	72.6
Hot Surface	69.8	69.6	69.5	70.9
Cold Surface	20.3	20.8	21.4	20.7
Cold Air	16.2	17.8	18.3	17.8
Surface/Surface, Mean	45.1	45.2	45.5	45.8
Surface/Surface, ΔT	49.5	48.8	48.1	50.2
RESISTANCE BTU^{-1}/hr/sq ft/$^{\circ}$F				
Hot Air Film	0.6	0.6	0.6	0.6
Surface/Surface	12.7	19.1	18.9	19.1
Cold Air Film	1.1	1.2	1.2	1.1
Total	14.4	20.9	20.8	20.9
CONDUCTANCE BTU/hr/sq ft/$^{\circ}$F				
Surface/Surface	0.079	0.052	0.053	0.052
Air/Air	0.069	0.048	0.048	0.048
COMPARISON				
Effect of Anomaly on Surface/Surface "R"	-34%	nil	nil	
Calculated Effect of Anomaly on Surface/Surface "R" (at 75°F mean)	-39%			

The differences between the results from Ceiling Test Panels No. 7, No. 9, and No. 10 are insignificant, and show that these anomalies (1-inch overlap, and ceiling electric fixture) had negligible effect on the measured heat loss and overall thermal resistance. In contrast, the effect of a 2-inch uninsulated area (4.2 percent of the insulated portion of the test area) was a reduction in the "R" factor by 34 percent. This is equivalent to an increase in heat loss of 50 percent.

The expected change in surface to surface thermal resistance due to the uninsulated area was calculated for Test Panel No. 8. This showed about a 39 percent reduction in R factor, depending on the assumptions made. Considering the sensitivity of thermal resistance to the amount of uninsulated area, and the difficulty of maintaining exactly the uninsulated area with a high degree of precision, the agreement between the measured and the calculated values is considered good.

It should be emphasized that the observed effect of the anomalies on the thermal performance was with "ideal" anomalies. As pointed out in TEST PANEL CONSTRUCTION, the highest quality of workmanship normally expected in residential construction was used. This was necessary in order to have a definition of test conditions and reproducibility. With some of the anomalies, especially where the opportunity for convection currents is present, poorer quality of workmanship would be expected to

significantly reduce the measured thermal performance. This could well be a profitable area for further investigation.

CONCLUSIONS

A. With "ideal" construction anomalies, the thermal performance of residential structures can be significantly poorer than that predicted by ASHRAE calculations that do not consider these effects.

B. Test results of wall structures without anomalies confirmed ASHRAE calculated thermal performance for both R-11 and R-7 insulation in the wall cavity.

C. The good agreement between measured and calculated thermal performance of wall structures required the use of actual test data in the calculations for the thermal resistance of the insulation, gypsum board facing, sheathing, etc.; using ASHRAE "nominal" values, the agreement between measured and calculated performance was less close, but still probably satisfactory for most engineering purposes.

D. The small remaining discrepancy could be caused by thermal short circuits of the metal fastenings (nails, screws) for the gypsum board and sheathing to the studs; from a practical standpoint this effect is of small consequence.

E. Due to the effect of temperature on the thermal performance of wall structures, the actual heat loss under typical winter conditions ($45^{O}F$ mean) is about 10 percent less (better) than that predicted under nominal conditions ($75^{O}F$ mean); under summer conditions ($95^{O}F$ mean), the performance is about 10 percent greater (poorer) than under nominal conditions.

F. A wall structure with R-11 insulation, but with 4.2 percent of the insulation test area uninsulated, had 13 percent less thermal resistance than the reference wall fully insulated.

G. Calculations of the expected thermal performance with the above anomaly confirmed the 13 percent decrease in "R" value.

H. Addition of an electrical box to an R-11 insulated wall had negligible effect on the thermal performance.

I. Because of the air spaces on either side of the insulation in a wall cavity with R-7 insulation, anomalies in an R-7 insulated wall affected thermal performance to a more serious degree than with an R-11 insulated wall.

J. With 4.2 percent uninsulated area, located at the top and bottom of the test area to encourage natural convection, the thermal performance of an R-7 wall was reduced 38 percent (heat loss increased 59 percent).

K. Addition of an electrical box to a wall with R-7 insulation reduced the "R" value by 9 percent.

L. Agreement between measured and calculated thermal performance for R-19 insulated ceiling structures was not as close as was found for walls.

M. At the same mean temperature, the thermal resistance of ceiling structures, with heat flow up was about equal to that with heat flow down; this was expected from the calculated thermal performance.

N. With 4.2 percent uninsulated area, the thermal performance of a R-19 insulated ceiling was reduced 34 percent (heat loss increased 50 percent).

O. Calculations of the expected change in thermal performance with the above anomaly confirmed approximately the observed results.

P. The loss in overall performance with small gaps in ceiling insulation is probably more serious than most installers are aware of.

Q. With careful installation, neither a 1-inch insulation overlap nor an added electrical box had an appreciable effect on the thermal performance of a R-19 insulated ceiling structure.

APPENDIX A FHA MINIMUM PROPERTY REQUIREMENTS FOR INSULATION (1954)

FIGURE 1

MINIMUM PROPERTY REQUIREMENTS
FOR PROPERTIES OF
ONE OR TWO LIVING UNITS

LOCATED IN SIX
ROCKY MOUNTAIN STATES
(Portion)

This edition includes MPR
Revisions Nos. 1 through 51

FEDERAL HOUSING ADMINISTRATION

BOISE, IDAHO INSURING OFFICE
CASPER, WYOMING INSURING OFFICE
DENVER, COLORADO INSURING OFFICE
HELENA, MONTANA INSURING OFFICE
RENO, NEVADA INSURING OFFICE
SALT LAKE CITY, UTAH INSURING OFFICE

FHA Form 2232. Revised December 1954

401–K. Common Services and Facilities. Two living units included under one mortgage may have common services such as water, sewer, gas, and electricity, and common facilities such as laundry, storage and heating, except that recirculating warm air from one living unit to another is not acceptable.

INSULATION AND VAPOR BARRIERS

402–A. Insulation.

1. The total hourly heat loss of a living unit in Btu shall not exceed 60 times the floor area in square feet. The floor area shall include closets and interior partitions, but not exterior walls or partitions exposed to unheated spaces.

2. In addition the over-all coefficient of heat transmission in Btu per hour per square foot per degree temperature difference from air inside to air outside or to air in unheated spaces (*"U"* factor) shall not exceed:

a. 0.15 for a ceiling or portion thereof exposed to an unheated space.

b. The values listed in the following table for exterior walls or partitions exposed to unheated spaces, and for floors over unheated spaces, for the outside design temperature established by the Federal Housing Administration for the locality.

Outside design temperature °F.	*Walls "U" factor*	*Floors "U" factor*
−36 and lower	0.15	0.06
−26 to −35 inclusive	.19	.10
−16 to −25 inclusive	.23	.16
−6 to −15 inclusive	.27	.22
−5 to +5 inclusive	.31	.28
+6 to +15 inclusive	.35	.28
+16 to +25 inclusive	.40	.34
+26 to +35 inclusive	.45	.42
+36 and higher	.50	.50

3. The Chief Underwriter may require insulation in excess of 1 and 2 above.

4. For insulation of concrete slabs on ground see 406–E–3.

5. Labeling.

a. Materials of batt or blanket type of insulation shall be clearly labeled showing:

(1) Name of manufacturer or national distributor, and
(2) Thickness (inches) with maximum variations that may exist.

b. Materials utilizing reflective type of insulation shall be clearly labeled showing:

(1) Name of manufacturer or national distributor, and
(2) Catalogue name and number.

NOTE.—*If the labeling is not printed at regular intervals on the material, at least one label shall be attached on or between joists, studs or rafters for each 40 lineal feet of insulation installed between framing members.*

APPENDIX B

FIGURE 2

All Weather Comfort Standard

Recommended practices for insulating, ventilating, shading and related factors for improved comfort and economy in electrically heated and/or air conditioned homes.

Paul W. Emler, vice president, American Electric Power Service Corp., New York, N. Y., in a speech at the First National Electric House Heating Exposition, Chicaqo, on March 21st, introduced and described the new All Weather Comfort Standard for electrically heated and/or air conditioned homes. Here are some pertinent excerpts from his talk, followed by the Standard, itself.

IN September of 1959 a round table, attended by representatives of the insulation, glass and electric heating equipment manufacturers, NEMA, NMWA, EEI, and the utilities, was held to discuss the insulation problem. A small representative committee took on the task of developing workable insulation standards. This committee had the valuable assistance of what I will call a shirt-sleeve committee the technical people from many of the companies represented at the insulation round table. As a result of this work, the new All Weather Comfort Standard for electrically heated and air conditioned homes which we are presenting today was born. This Standard is, I believe, completely practical and workable, and meets the shortcomings of our previous recommendations for insulating the electrically heated and air conditioned home.

Performance is the key to the new Standard---performance measured two ways. The first is over-all performance—the Btuh heat loss based on the total square foot area of the house. This is not just one loss figure for the entire country but rather various loss figures for different weather zones in the country. Values vary from 40 Btuh per square foot in an over 8000 degree day area to 28 Btuh per square foot in an under 3000 degree day area. In addition to this over-all heat loss figure, separate thermal performance values are recommended for the various structural parts of the house. If the thermal performance values recommended for the individual parts are actually attained, the total heat loss figure recommended will generally be achieved.

By using these two sets of thermal performance recommendations, the total heat loss of the house and individual thermal performance values for the various elements of the house, flexibility of design is possible which was not possible with our older recommendations. For example, if it is not practical to attain the recommended thermal performance in the house wall, it may be possible to add more than recommended insulation in the ceiling and thereby keep the total heat loss of the structure within the recommended limits. The objective is to control total heat loss and attain a satisfactory economical heating and cooling installation rather than to dictate specifically and rigidly the thermal performance of every element of the structure. On the other hand, it will be possible in many structures to keep the total heat loss below the figure suggested in the new Standard by insulating all elements of the structure so that their thermal performance will be equal to or better than values suggested in the Standard.

This new All Weather Comfort Standard has been submitted for acceptance to individual manufacturers of heating equipment, insulation, glass and air conditioning equipment, to trade associations such as National Electrical Manufacturers Association, National Association of Home Builders, National Mineral Wool Association, Air Conditioning and Refrigeration Institute, National Warm Air Heating and Air Conditioning Association and Edison Electric Institute, as well as a number of individual electric utilities. Many acceptances have already been received and the Standard is being considered by other individual companies and associations who have not yet made decisions.

At the present time there is no one official sponsor for the Standard but it is our plan to have it sponsored by a group which will officially represent the companies and associations having a direct interest in insulating the electrically heated and air conditioned home.

• • •

ALL WEATHER COMFORT STANDARD

Purpose

To encourage good insulation practice so the owner will benefit from:

1. Lower first cost of both heating and cooling equipment.
2. Lower operating cost for both heating and cooling.
3. Greater comfort for the occupants during both the heating and cooling seasons.

Objectives

To establish:

1. Recommended thermal performance values for electrically heated homes.
2. Recommend maximum summer heat gain for air-conditioned homes.
3. Responsibility for insulation quality and application.

RECOMMENDED THERMAL PERFORMANCE VALUES FOR ELECTRICALLY HEATED HOMES

When based on an infiltration rate of one air change per hour, the heat loss values in Table I, which are expressed in Btuh per sq ft of floor area of the space to be heated to the comfort level, measured to the outside of exterior wall, will generally be achieved with the thermal performance values recommended in Table II.

TABLE I—RECOMMENDED HEAT LOSS VALUES

Degree Days	Btuh per sq ft	Watts per sq ft
Over 8000	40	11.7
7001 to 8000	38	11.3
6001 to 7000	35	10.3
5001 to 6000	32	9.4
3001 to 5000	30	8.8
Under 3001	28	8.2

TABLE II—THERMAL PERFORMANCE VALUES FOR VARIOUS BUILDING SECTIONS

Building Section	U Value* Btu per (hr) (sq ft) (F)
Ceiling	0.05
Frame Walls	0.07
Masonry Walls	0.12
Floor over vented spaces	0.07
Floors over unheated basements	0.09
Slab edge heat loss	30 Btuh per linear foot

* Calculated in accordance with the method described in current ASHRAE Guide, before correction for framing.

These values may need improvement in severe climates, when ceiling heat is used or when glass areas constitute a larger percentage of gross wall area than provided for in the establishment of the values.

Weatherstripping, double glazing and storm doors should be used as required to meet the values in Table I and for comfort and operating economy.

It is recommended that infiltration, natural and mechanical ventilation, vapor barrier and slab on grade heat loss considerations be guided by the excerpts contained in the Appendix.

It is recommended that sections between regularly and periodically heated spaces be insulated when the temperature difference between them is expected to be more than 20 deg F.

It is recommended that fireplaces be provided with tight fitting dampers.

RECOMMENDED MAXIMUM SUMMER HEAT GAIN FOR AIR CONDITIONED HOMES

It is recommended that the total calculated heat gain to all space to be cooled to the comfort level not exceed 25 Btuh per sq ft of floor area of this space, measured to the outside of exterior walls, when calculated from the data contained in the current ASHRAE Guide.

It is recommended that consideration be given to shading glass areas by natural or mechanical means in order to minimize sun effect.

The recommended maximum heat gain value can generally be achieved with the performance values recommended in Table II when consideration is given to shading of glass areas.

RESPONSIBILITY FOR INSULATION QUALITY AND APPLICATION

The insulation manufacturer shall be responsible for the quality of material and when required shall certify to its performance when installed in accordance with his application standards.

The insulation applicator shall be responsible for installing the material in accordance with the manufacturer's recommendations and shall so certify when required to do so.

APPENDIX

INFILTRATION HEAT LOSS

Quoted from FHA Technical Circular No. 7, Revised August, 1959, "Heat Loss Calculations".

One air change per hour may be assumed a reasonable average for estimating the infiltration heat loss. Infiltration values calculated on the basis of the "crack method" are considered acceptable, provided the result is not less than the equivalent of ½ air change per hour.

VENTILATION OF STRUCTURAL SPACES

Objective

To provide natural ventilation of spaces such as attics and basementless spaces to minimize the effect of conditions conducive to decay and deterioration of the structure and to reduce attic heat in the Summer.

General

Net free area of an opening is the total unobstructed area through which air can pass.

Basementless Spaces (Crawl Spaces)

At least 4 foundation wall ventilators shall be provided, one located close to each corner of the space, having an aggregate net free ventilating area not less than 1/150 of the area of the basementless spaces; or

Ground surface treatment shall be provided in the form of a vapor barrier material plus at least 2 foundation wall ventilators having an aggregate net free ventilating area not less than 1/150 the area of the basementless space.

Attics and Spaces Between Roofs and Top Floor Ceilings

Provide cross ventilation for each separate space by ventilating openings protected against the entrance of rain and snow.

Ratio of total net free ventilating area to area of ceiling shall be not less than 1/150, except that ratio may be 1/300 provided:

a. A vapor barrier having a transmission rate not exceeding one perm is installed on the warm side of the ceiling; or

b. At least 50% of the required ventilating area is provided by ventilators located in the upper portion of the space to be ventilated (at least 3'-0" above eave or cornice vents) with the balance of the required ventilation provided by eave or cornice vents.

MECHANICAL VENTILATION

Objective

To provide mechanical ventilation for bathrooms and kitchens not ventilated by natural means.

Bathrooms

Fan shall have sufficient capacity to provide a minimum of twelve air changes per hour.

TABLE 10-1—SLAB EDGE HEAT LOSS FACTORS

Outdoor design temperature (Deg F)	Total width of insulation (inches)	Heat Loss Coefficient, F (Btuh per linear foot of exposed slab edge) — Unheated Slab R = 5.0	Unheated Slab R = 3.33	Unheated Slab R = 2.50	Heated Slab R = 5.0	Heated Slab R = 3.33	Heated Slab R = 2.50
−30 and colder	24	34	51	67	46	69	92
−25 to −29	24	32	48	64	44	66	88
−20 to −24	24	30	45	60	41	61	82
−15 to −19	24	28	43	57	39	59	78
−10 to −14	24	27	40	54	37	55	74
− 5 to − 9	24	25	38	51	35	52	70
0 to − 4	24	24	36	48	32	48	64
+ 5 to + 1	24	22	33	44	30	45	60
+10 to + 6	18	21	31	42	25	38	50
+15 to +11	12	21	31	42	25	38	50
+20 to +16	edge only	21	31	42	25	38	50

Notes:
R = Thermal Resistance of Insulation.
Use F = 40 for unheated slabs or F = 75 for heated slabs, if perimeter insulation is not used.
Table from F.H.A. Circular No. 300, Minimum Property Standards for 1 and 2 Living Units.

Kitchens

Fan shall have sufficient capacity to provide a minimum of 15 air changes per hour in area occupied by kitchen.

VAPOR BARRIERS

Walls

A vapor barrier shall be installed on the warm side of the walls when the U value of the wall is numerically less than 0.25.

Ceilings

Install on warm side of ceiling when a vapor barrier is provided.

Roof Deck

When roof deck material is also the finished ceiling, a vapor barrier having a vapor permeance of not more than ½ perm shall be installed near the warm side of the construction in areas having a design temperature of 10 deg F or lower.

Concrete Slabs and Basementless Spaces

Maximum vapor permeance shall not exceed ½ perm for vapor barrier under concrete slabs and 1 perm for ground cover in crawl spaces.

SLAB ON GRADE HEAT LOSS

Calculations of heat loss through concrete slab floors shall be made using the following formula:

$H = F \times P$ where:

H = heat loss of the floor, Btuh

F = heat loss coefficient, Btuh per linear foot of exposed edge, from Table 10-1.

P = perimeter or exposed edge of the floor, linear feet.

Here's what NMWA did with the All Weather Comfort Standard

NATIONAL Mineral Wool Association member companies first decided to accept the All Weather Comfort Standard. Then they unanimously voted to recommend "installed resistance" designations as a means of showing which specific mineral wool products are suitable for ceiling, wall or floor application.

According to F. H. Sides, NMWA executive officer, the definition of "installed resistance, R" is the resistance of the mass insulation itself, plus the resistance values of the air spaces and surfaces that come into existence when the insulation is installed. He added that NMWA is recommending to its members that in the future they mark all mineral wool batts and blankets with appropriate "R" numbers. When a particular product is suitable for use in different structural sections of a house, considering the different directions of heat flow involved, the labeling will include "R" factors for each application.

How is "R" determined? Merely by taking the reciprocal of the recommended "U" value for any structural section to convert it into total units of resistance. From this, you subtract the inherent thermal resistance values of the building materials used in that structural section (siding, sheathing, wallboard or plaster, etc.), plus the value of the room-side surface resistance. The balance is the installed resistance requirement of the insulation, denoting the "R" labeling of the product that should be used.

For typical ceiling, wall and floor sections, Table A shows the "R" values which conform to the "U" values of the All Weather Comfort Standard for electrically heated and/or air conditioned homes. In addition, it presents NMWA-recommended "U" and "R" values for gas or oil heating and for minimum acceptable comfort.

TABLE A—RECOMMENDED INSTALLED RESISTANCE (R) VALUES OF INSULATION

Building Section	Electric Heating and/or Air Conditioning U	Electric Heating and/or Air Conditioning R	Gas or Oil Heating (No Air Conditioning) U	Gas or Oil Heating (No Air Conditioning) R	Minimum Acceptable Comfort U	Minimum Acceptable Comfort R
Ceilings	.05	19	.07	13	.10	9
Frame Walls	.07	11	.09	8	.11	7
Floor over vented Crawl spaces	.07	13	.09	9	.11	7

Example: Insulation applied to typical wall construction for an electrically-heated home should be labeled R-11. This fulfills total resistance requirement for U value of .07 Btu per (hr)(sq ft)(°F).

APPENDIX C

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MINIMUM PROPERTY STANDARDS

for

ONE AND TWO LIVING UNITS

(Portion)

U. S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
FEDERAL HOUSING ADMINISTRATION
Washington, D. C. 20410

FHA No. 300

(REPRINTED TO INCLUDE GENERAL REVISION No. 5, DATED JANUARY 1965)

713 VAPOR BARRIERS

713–1 Test data indicating the vapor transmission rate determined in accordance with ASTM dry cup methods may be required for barriers used in walls and ceilings.

713–2 WALLS

Except for unfurred masonry walls, a vapor barrier having a vapor transmission rate not exceeding 1 perm shall be installed on the warm side of the walls when:

a. The "U" value of the wall is numerically less than 0.25, or

b. The wall has siding, sheathing, sheathing paper, or combinations of other materials on the cold side of the wall which materials, as applied, have a vapor transmission rate of less than 5 perms (ASTM dry cup).†

713–3 CEILINGS

When a vapor barrier is provided in ceilings, transmission rate of vapor barrier shall not exceed 1 perm. Install on warm side of ceiling. See 604–4.

713–4 ROOF DECK

713–4.1 When a wood plank, fiberboard, or other roof deck material is also the finished ceiling surface, a vapor barrier having a vapor permeance of not more than ½ perm shall be installed near the warm side of the construction in areas having a design temperature of 10 degrees F. or lower.

713–4.2 Joints at sides and ends of fiberboard roof deck shall be designed to provide effective sealing of vapor barrier.

713–5 CONCRETE SLABS AND BASEMENTLESS SPACES

713–5.1 Materials used for vapor barriers shall comply with FHA "Test Procedure for Vapor Barrier Materials under Concrete Slabs and for Ground Cover in Crawl Spaces", dated September 20, 1957.

713–5.2 Test data indicating compliance may be required.

713–5.3 Maximum vapor permeance shall not exceed:

a. ½ perm for vapor barrier under concrete slabs.
b. 1 perm for ground cover in crawl spaces.

714 THERMAL INSULATION

714–1 STANDARDS

Installations shall comply with the following:

714–1.1 Batts, Blankets, etc.:

Structural fiber insulation board	C.S. 42
Wood fiber blanket	C.S. 160
Mineral wool	F.S. HH–I–521
Vegetable or wood fiber	F.S. HH–I–515
Redwood bark, shredded	F.S. LLL–I–533
Vermiculite	F.S. HH–I–585
Cotton batts	F.S. HH–I–528
Expanded polystyrene insulation board	F.S. HH–I–524

Insulations, such as reflective types, combination reflective batt or blanket type mineral wool blankets, low-density mineral wools, and other materials not covered by existing standards may be considered for use on the basis of tests conducted in accordance with ASTM, C.S. 131 or other recognized methods.

714–1.2 Roof Insulation

Fiberboard	ASTM C–208, Class C or F.S. LLL–I–535
Cellular glass	F.S. HH–I–551a
Corkboard	F.S. HH–I–561b
Mineral wool	F.S. HH–I–526a
Expanded perlite	F.S. HH–I–526a modified to permit the basic material to be a mineral substance made of rock, slag, or a mixture thereof, processed from a natural state into fibrous or cellular form with a minimum density of 8 pounds per cubic foot.†

714–1.3 Fiberboard insulating roof deck shall comply with FHA Use of Materials Bulletin, No. UM–29, "Structural Fiberboard Insulating Roof Deck."†

714–1.4 Vermiculite fill insulation for masonry cavity walls shall comply with FHA Use of Materials Bulletin, No. UM–30, "Vermiculite Water-Repellent Masonry Fill Insulation."†

714–1.5 Perimeter insulation shall comply with FHA test procedure, "Test Procedures to Determine Acceptability of Perimeter Insulation for Concrete Floor or Ground", dated June 1, 1956.†

714–2 LABELING

714–2.1 Batt or blanket type not having reflective surfaces

a. Name of manufacturer or distributor.
b. Specified thickness.

714–2.2 Reflective Type

a. Name of manufacturer or distributor.
b. Designation of type or number.

714–2.3 Combination batt or blanket with reflective surface

a. Name of manufacturer or distributor.
b. Specified thickness.
c. Designation of type or number.

714–2.4 Labeling may be by printing, stamping, embossing, or other means applied at the manufacturer's plant. Labeling shall be applied so that at least one label will occur for each 40 lineal feet of installed insulation.

714–2.5 Where blowing or pouring type insulation is used, a card signed by the builder shall be affixed to the structure adjacent to the insulation with the following information:

a. Name of manufacturer or national distributor and trade name of insulation.
b. Specified thickness of insulation and manufacturer's recommended installation density.
c. Date of installation.

714–3 INSULATION OF LIVING UNITS

Living units, other than those heated with electrical energy (direct or indirect resistance, or heat pump), shall comply with the following:

714–3.1 Total Heat Loss

The total calculated heat loss of the living unit shall not exceed 50 Btuh per sq. ft. of the total floor area of the space to be heated to 70° F. measured to the outside of exterior walls.

714–3.2 Heat Loss Through Ceilings

Ceiling below an unheated space shall have a maximum coefficient of heat transfer ("U" value for heat flow up) of:

a. 0.06 for ceilings with heating panels.
b. 0.15 for ceilings without heating panels.

714–3.3 Heat Loss Through Vertical Surfaces

The total heat loss (excluding infiltration loss) through all exterior walls, doors, windows, etc., shall not exceed 30 Btuh per sq. ft. of total floor area of the spaces to be heated to 70° F.

714–3.4 Heat Loss Through Floors

a. The heat loss through floors over unheated basements, crawl spaces, breezeways and garages shall not exceed 15 Btuh per sq. ft. of floor area. For the purpose of this requirement only, the following notes shall apply:

Note 1. A basement shall be considered unheated unless it is provided with a positive heat supply equivalent to at least 15% of the total calculated heat loss of the living unit, or contains the heating unit and uninsulated ducts or piping.

Note 2. A crawl space is considered unheated unless it is (a) provided with a positive heat supply equivalent to at least 10% of the total calculated heat loss of the living unit, or (b) contains uninsulated ducts or piping, or (c) is used as a supply or return plenum.

Note 3. A garage is considered unheated unless provided with a positive heat supply to maintain a minimum temperature of 50 degrees F.

b. Perimeter insulation shall be installed to limit the heat loss from heated or unheated concrete slab-on-grade floors to not more than 5 Btuh per sq. ft. of floor area except that perimeter insulation may be omitted in any area where the annual degree days do not exceed 2,800 or the heating degree days in any one month do not exceed 650. See 1003–3.3.

714–3.5 Crawl Space Plenums

Where a crawl space is used as a supply or return plenum, the crawl space perimeter wall shall be insulated to provide a maximum heat loss of 35 Btuh per lineal foot of perimeter wall assuming a crawl space air temperature of 70° F. for return plenums and 110° F. for supply plenums. See 1003–14.3c.

714–3.6 Blowing or pouring type insulation shall not be installed in attic space where clear headroom is less than 30 inches at a point 12 feet from exterior walls. When eave vents are installed, adequate baffling shall be provided.*

714–4 INSULATION OF LIVING UNITS (ELECTRICAL HEATING)

Living units heated with electrical energy shall comply with the following:

714–4.1 The total calculated heat loss of the living unit shall not exceed 40 Btuh per sq. ft. of total floor area of the spaces to be heated to 70 degrees F. measured to the outside of exterior walls.

714–4.2 Paragraphs 714–3.2 through 714–3.6 inclusive shall apply to electrically heated houses.

714–5 INSULATION OF LIVING UNITS FOR COOLING

714–5.1 When air conditioning equipment is proposed, the calculated heat gain of the living units shall not exceed that obtained when the floor area, measured to the outside of the exterior walls, is multiplied by the Btuh per square foot value derived through use of Figure No. 7-b.

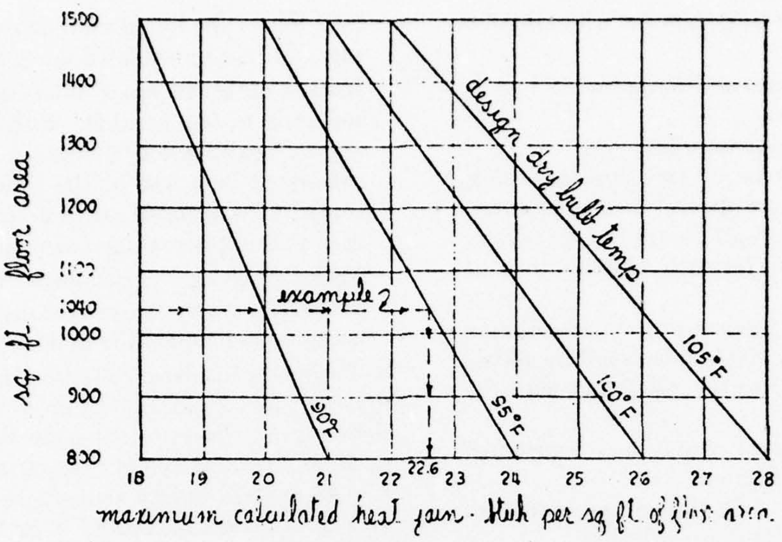


FIGURE 7b

Note: The Btuh per square foot is obtained by extending a line horizontally from the point of intersection with the appropriate design dry bulb temperature line. From this point extend a vertical line down to the bottom of the chart and find the maximum Btuh per square foot heat gain. The example shown on the chart represents a living unit with a floor area of 1040 square feet in a geographic area having a design dry bulb temperature of 95° F. By following the dotted lines in the direction of the arrows, it will be seen that a maximum heat gain of 22.6 Btuh per square foot of floor area is permitted. Thus, the maximum heat gain of the example living unit is 22.6×1040=23,504 Btuh.

714–5 Insulation of Living Units for Cooling—Con.

a. The Btuh per square foot of floor area value shown in Figure No. 7-b for living units of 1500 square feet shall apply to living units of more than 1500 square feet.

b. The Btuh per square foot of floor area value shown in Figure No. 7-b for living units of 800 square feet shall apply to living units of less than 800 square feet.

c. When the outside design dry bulb temperature is less than 90° F. the value shown in Figure No. 7-b for 90° F. shall be used.

d. When the outside design dry bulb temperature is more than 105° F. the values shown in Figure No. 7-b for 105° F. shall be used.

714–5.2 Ceilings below attics or top floor structural spaces shall have a maximum coefficient of heat transfer ("U" value for heat flow down) of 0.08.

715 RESILIENT FLOORING

715–1 GENERAL

715–1.1 Resilient flooring shall comply with the appropriate standard as noted.

715–1.2 The various types of resilient flooring shall be suitable for their intended use.

715–2 ASPHALT TILE

715–2.1 Minimum thickness, 1/8 inch.

715–2.2 Asphalt tile shall comply with F.S. SS–T–306 or SS–T–307.*

715–3 VINYL-ABESTOS TILE

715–3.1 Minimum thickness, 1/16 inch.

715–3.2 Vinyl-asbestos tile shall comply with interim F.S. L–T–00345 except for thickness.

715–4 HOMOGENEOUS VINYL TILE OR SHEET (UNBACKED)

715–4.1 Minimum thickness, 0.0625 inch (appx. 1/16 inch).

715–4.2 Homogeneous vinyl tile or sheet shall comply with interim F.S. L–F–00450 except for thickness.

715–5 BACKED VINYL TILE OR SHEET

715–5.1 Wearing Surface:

a. Clear (unfilled) vinyl, minimum thickness, 0.014 inch.

b. Filled vinyl, minimum thickness, 0.020 inch.

714 THERMAL INSULATION

714-1 STANDARDS

Installations shall comply with the following:

714-1.1 * Batts, Blankets, etc:

Structural fiber insulation board	C.S. 42
Wood fiber blanket	C.S. 160
Mineral wool	F.S. HH-I-521
Vegetable or wood fiber	F.S. HH-I-515
Redwood bark, shredded	F.S. LLL-I-533
Vermiculite	F.S. HH-I-585
Cotton batts	F.S. HH-I-528
Perlite	F.S. HH-I-574a
Expanded polystyrene insulation board	F.S. HH-I-524
Mineral fiber, pouring or blowing type	F.S. HH-I-1030

Insulations, such as reflective types, combination reflective batt or blanket type mineral wool blankets, low-density mineral wools, and other materials not covered by existing standards may be considered for use on the basis of tests conducted in accordance with ASTM, C.S. 131, or other recognized methods.

(No change in 714-1.2, -1.3 and -1.5)

714-1.4 Vermiculite and perlite fill insulations for masonry walls shall comply with their respective Use of Materials Bulletin, Nos. UM-30 and UM-37.

* * *

715 RESILIENT FLOORING

715-1 GENERAL

715-1.1 Resilient flooring shall comply with the appropriate standard as noted.

715-1.2 The various types of resilient flooring shall be suitable for their intended use.

715-2 ASPHALT TILE

715-2.1 * Asphalt tile shall comply with F.S. SS-T-312, Type I.

715-2.2 * Minimum thickness, 1/8 inch.

715-3 VINYL-ASBESTOS TILE

715-3.1 * Vinyl-abestos tile shall comply with F.S. SS-T-312, Type IV except for thickness.

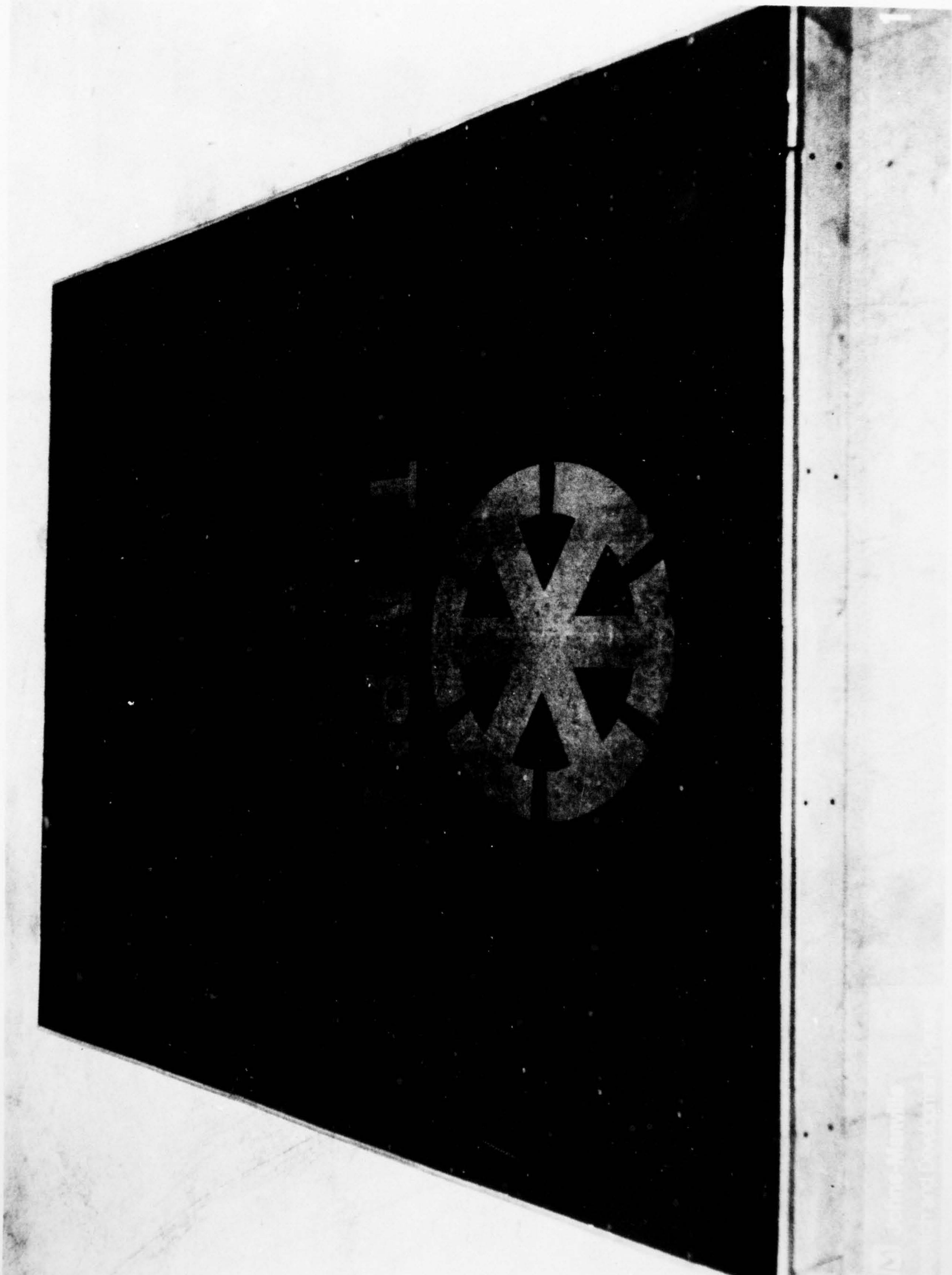
* Revised August 1968

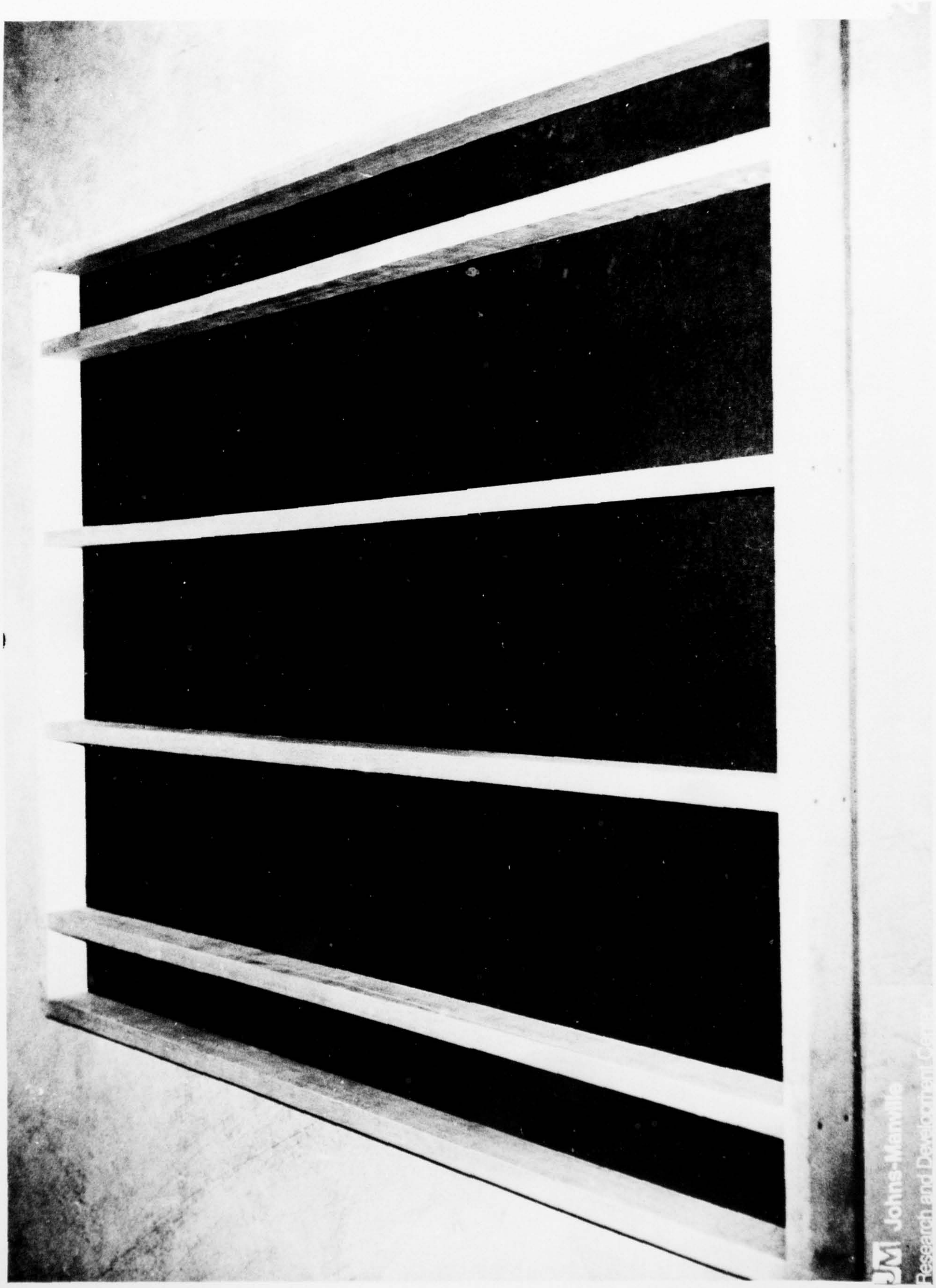
APPENDIX D PHOTOGRAPHIC DOCUMENTATION

PHOTOGRAPHIC DOCUMENTATION

Identification: Photo Number	Identification: Test Panel Number	Detail
1	1	Sheathing Face
2	1	Wall Cavity Before Being Insulated
3	1	R-11 Insulation Being Installed
4	1	Completed Insulation & Vapor Barrier Installation
5	1	1/2-Inch Gypsum Board Being Installed
6	1	Completed Reference Test Panel, (Gypsum Board Face, Panel No. 7 & No. 4 Similar)
7	1	1/2-Inch Gypsum Board Edge Protection Detail
8	4	Wall Cavity Before Being Installed
9	4	Detail Outside Convection Barriers & String Insulation Support (String Support Subsequently Added to 8-Inch Wide Cavities)
10	4	R-7 Insulation Being Installed
11	4	Completed Insulation & Vapor Barrier Installation
12	4	Detail Warm Side Convection Barrier
13	7	Ceiling Cavity Before Being Installed
14	7	Detail Convection Barrier & String Insulation Support
15	7	R-19 Insulation Partially Installed
16	7	Vapor Barrier (Separate) Installed

Photo Number	Test Panel Number	Detail
17	7	Attic Side of R-19 Insulation (original construction - superseded by details shown in Photos 29-31; see text)
18		Guarded Hot Box Apparatus - Warm Side Showing Metering Box & Surrounding Guard Box
19		Guarded Hot Box Apparatus - Cold Box Side
20		Installation Test Panel No. 1 in Guarded Hot Box Apparatus
21		Warm Surface Temperature Thermocouples (Cold Surface Similar)
22		Completed Guarded Hot Box Installation
23		Guarded Hot Box Control Panel
24	2	R-11 Wall With 2-Inch Wide Uninsulated Area
25	5	R-7 Wall With 2 1-Inch Wide Uninsulated Areas
26	3	R-11 Wall With Electrical Box Installed
27	6	R-7 Wall With Electrical Box Installed
28	6	Completed R-7 Wall Test Panel With Electrical Receptacle Installed (Test Panel No. 3 Similar)
29	8	R-19 Ceiling With 1 12-Inch Wide Uninsulated Area
30	9	R-19 Ceiling With Batt Overlapped 1-Inch
31	10	R-19 Ceiling With Electrical Box Installed
32	10	Completed R-19 Ceiling Test Panel With Ceiling Electrical Fixture Installed

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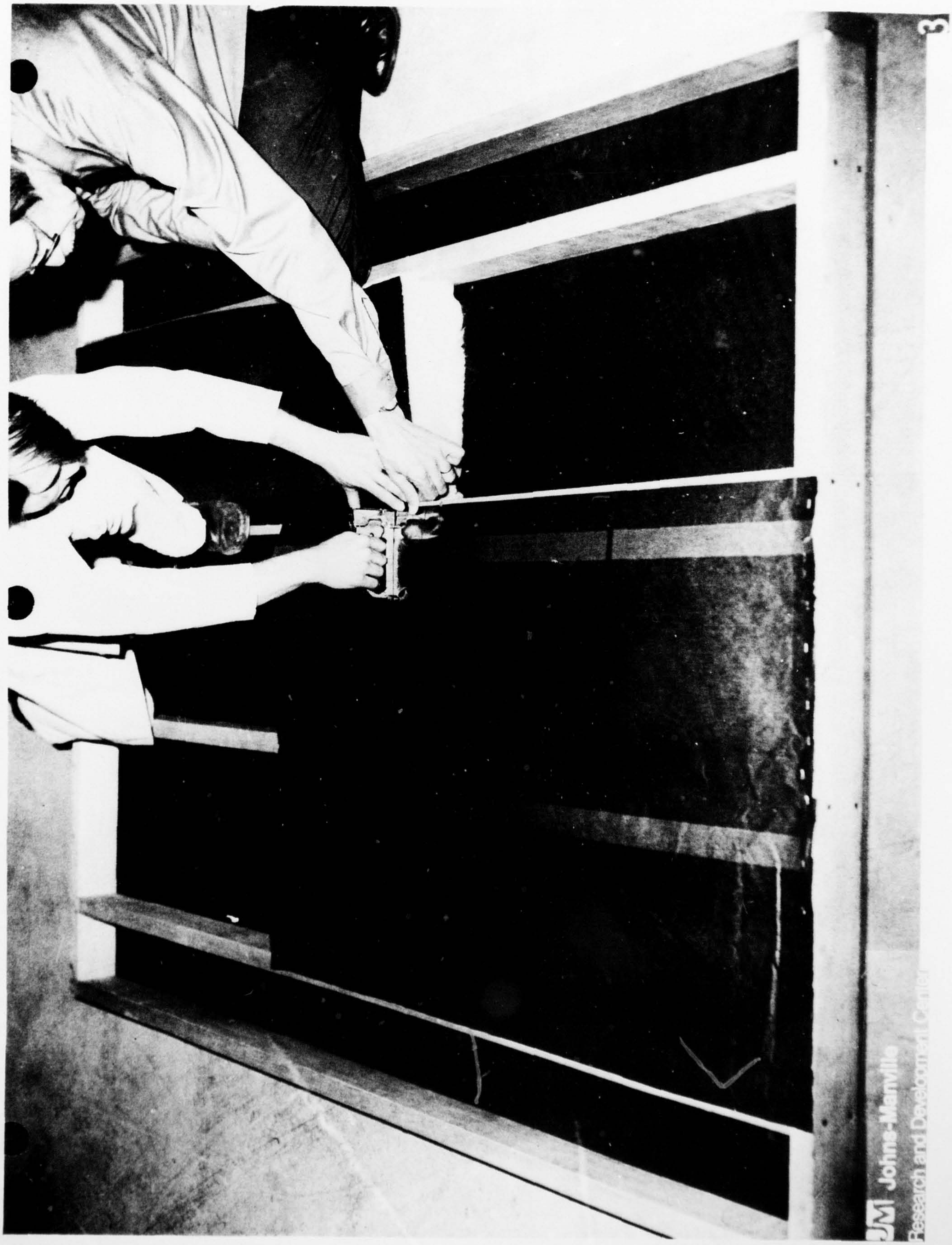
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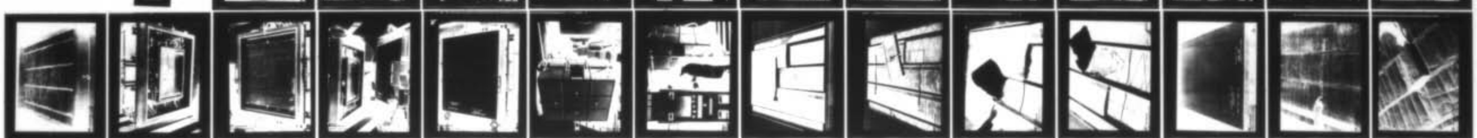

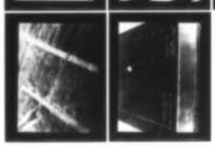

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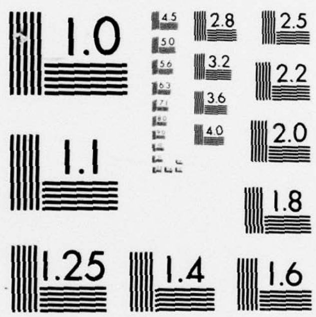

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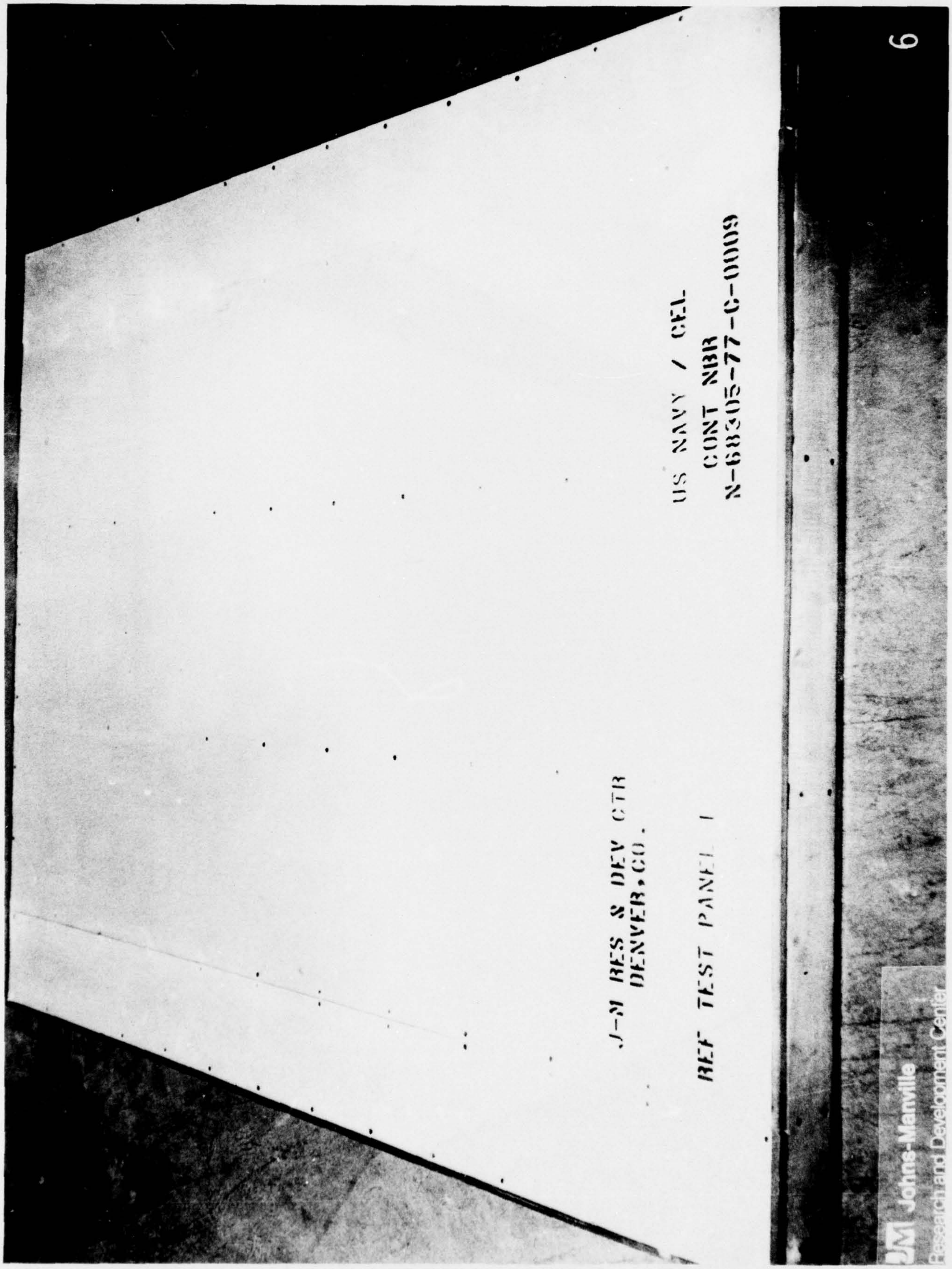
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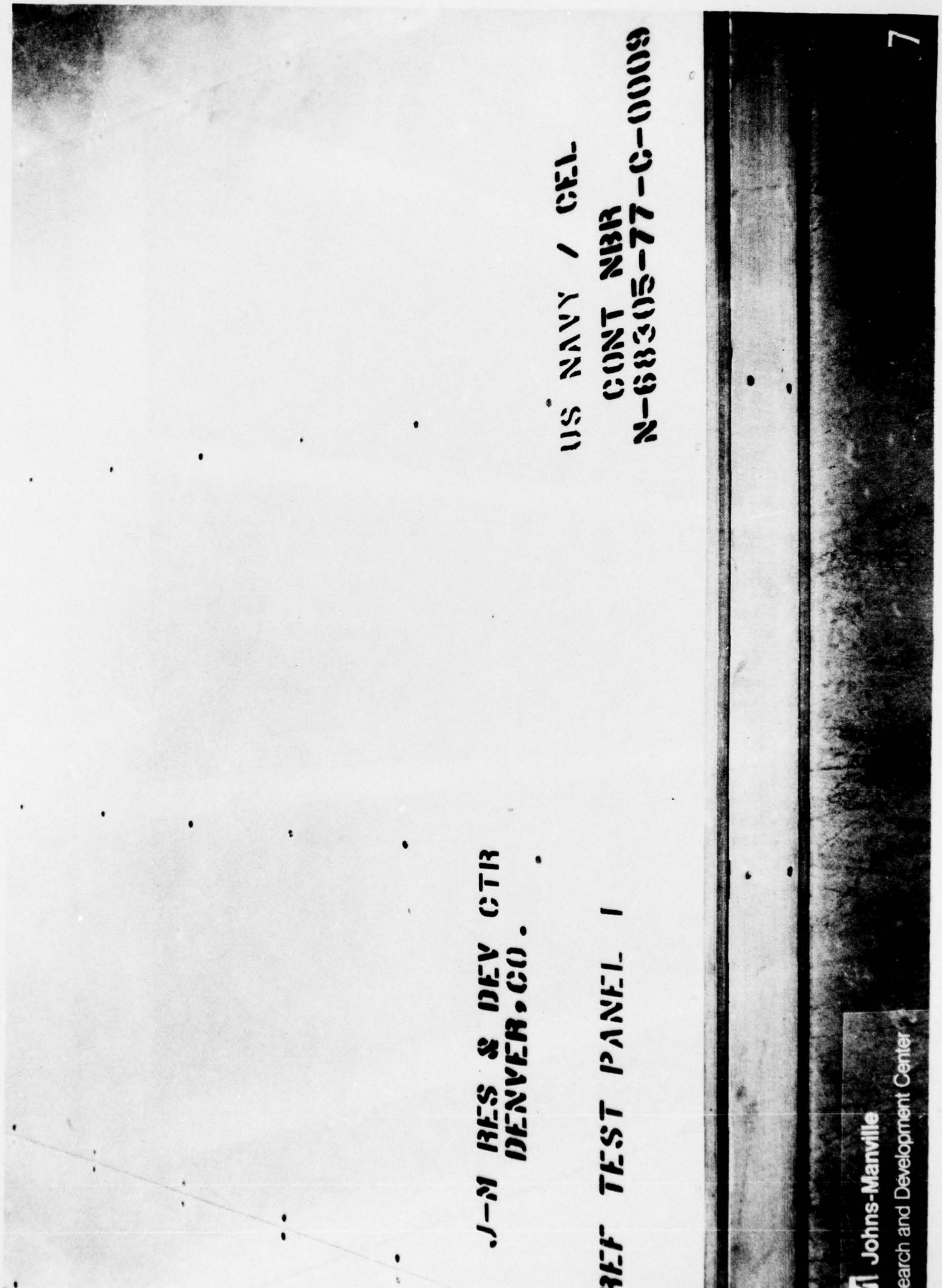
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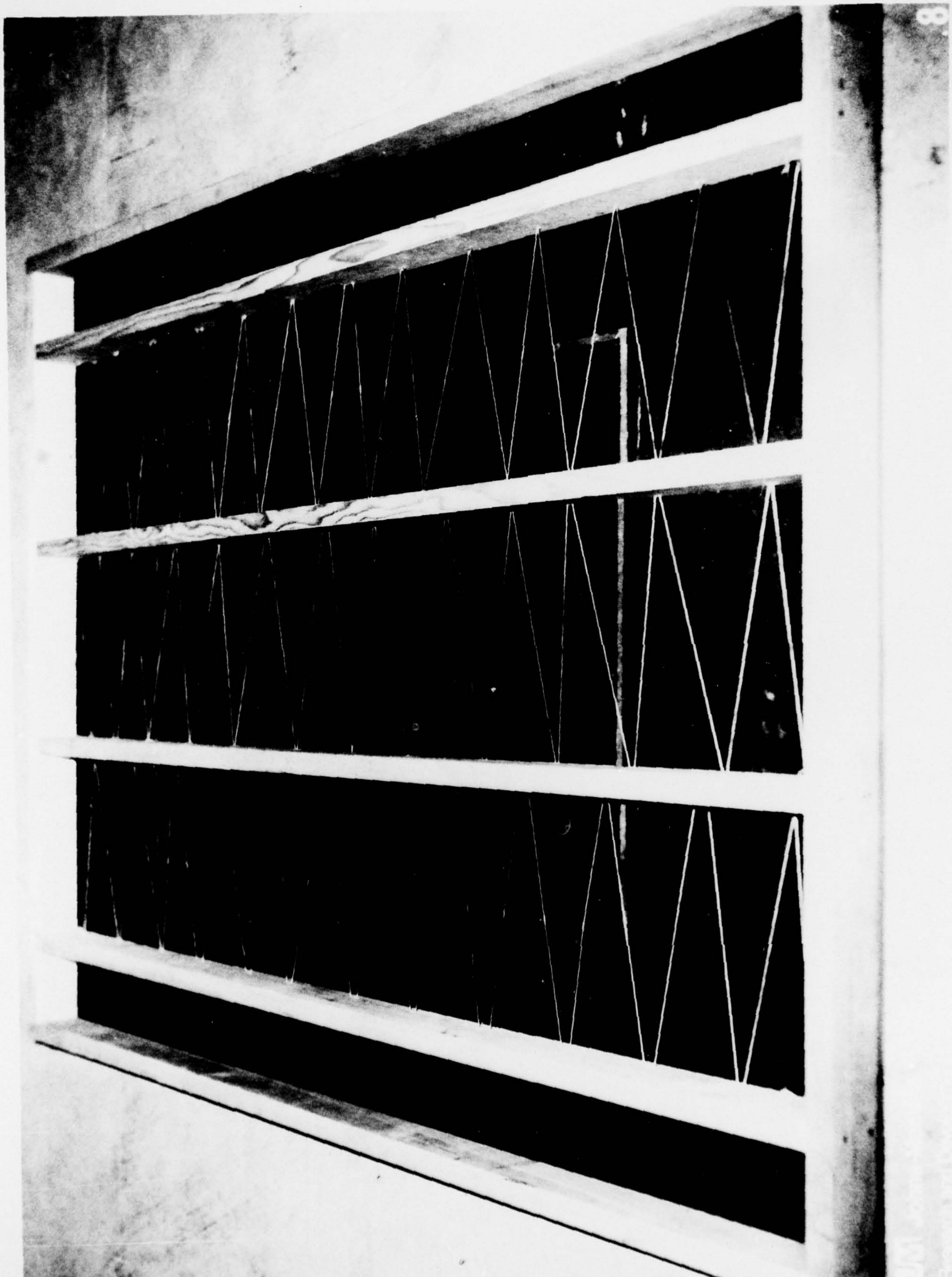


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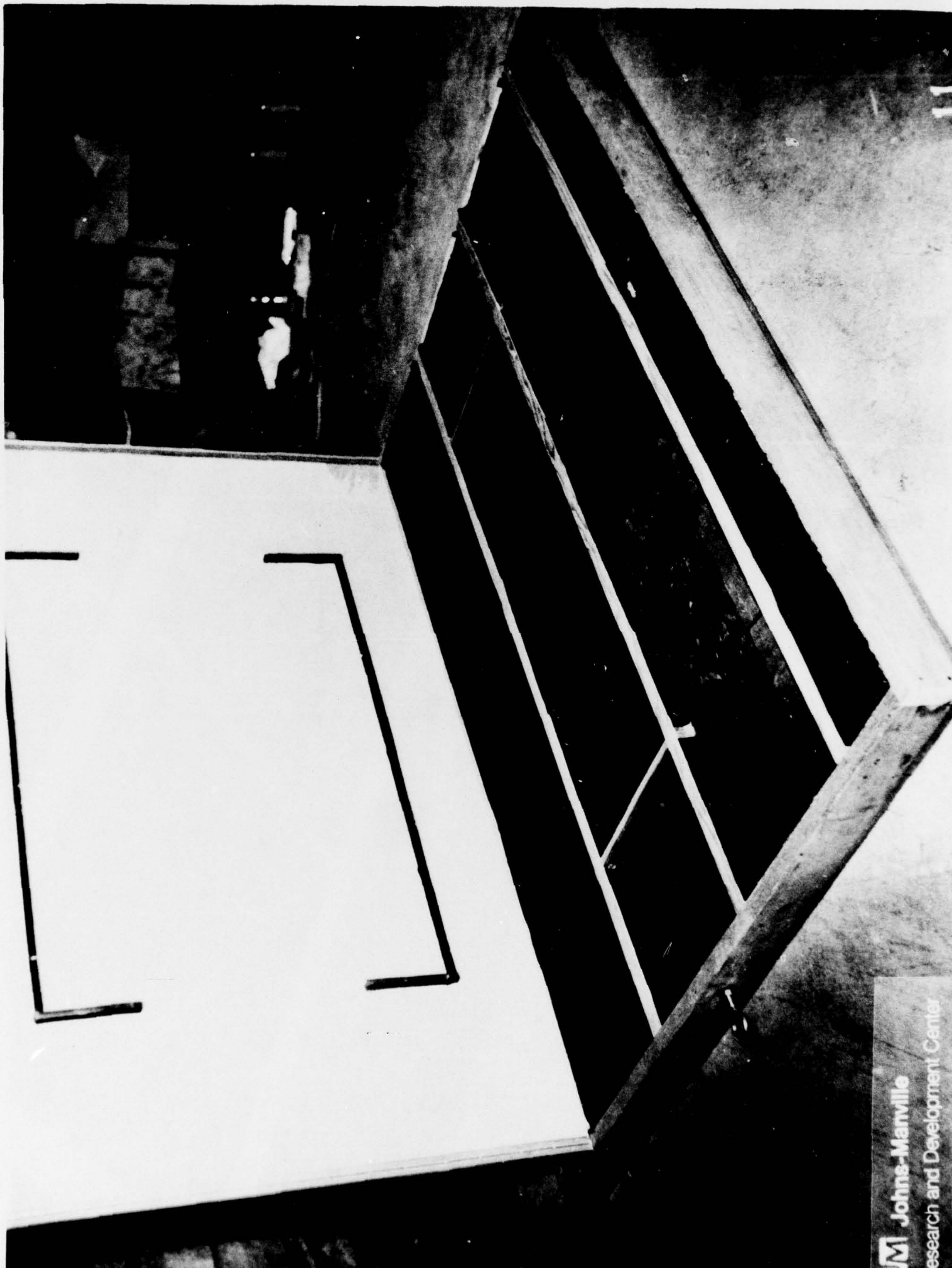
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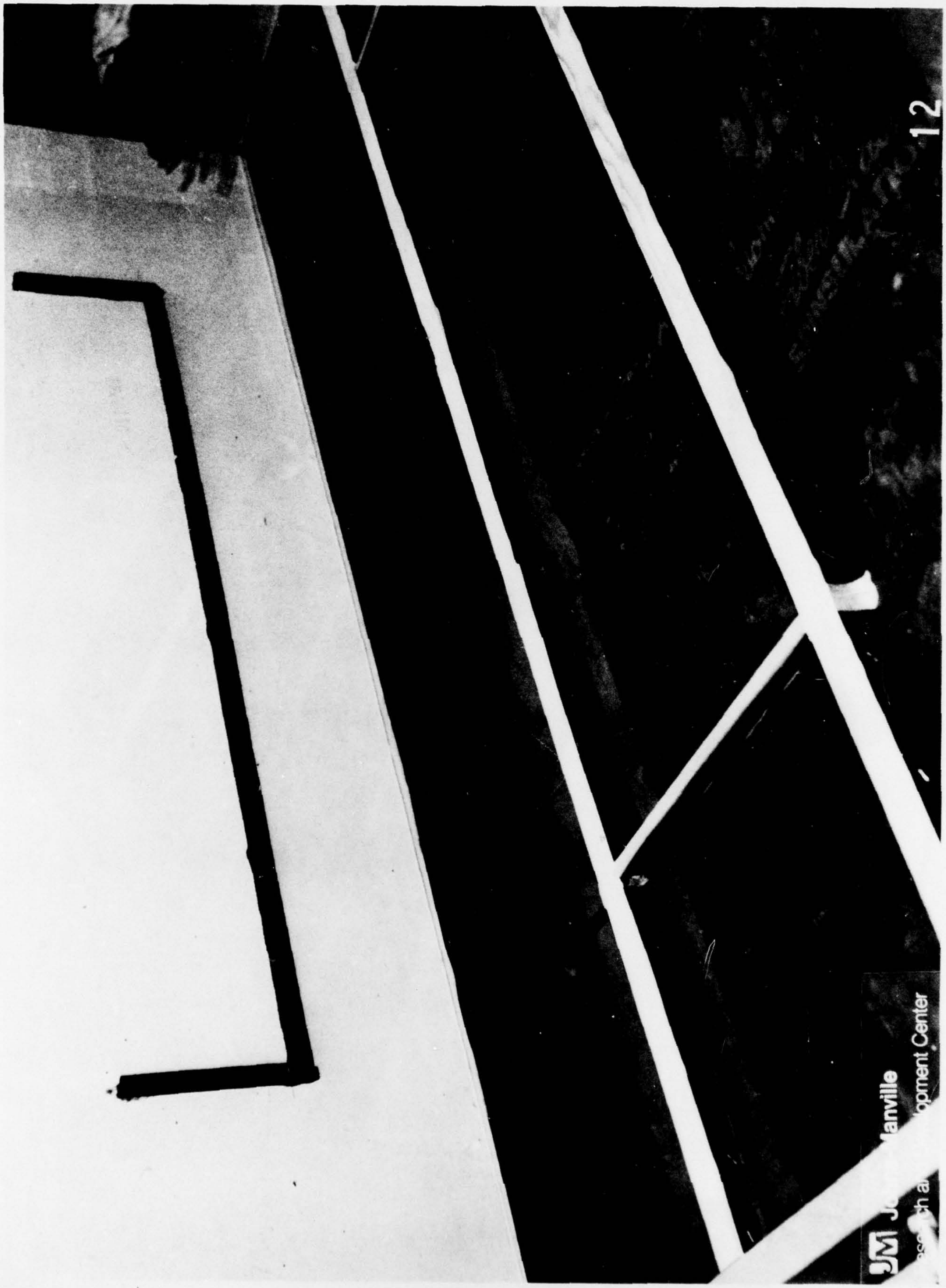
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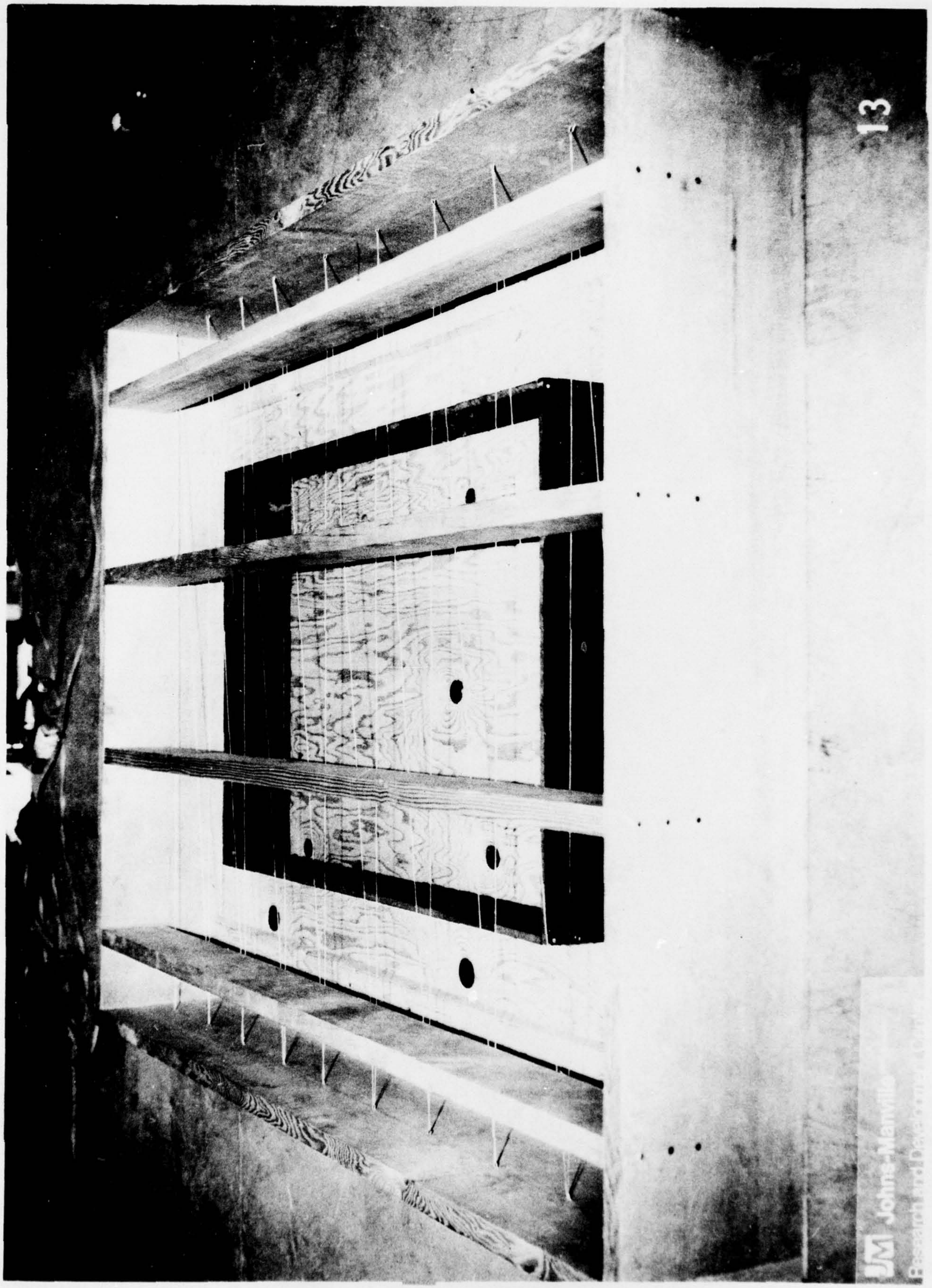
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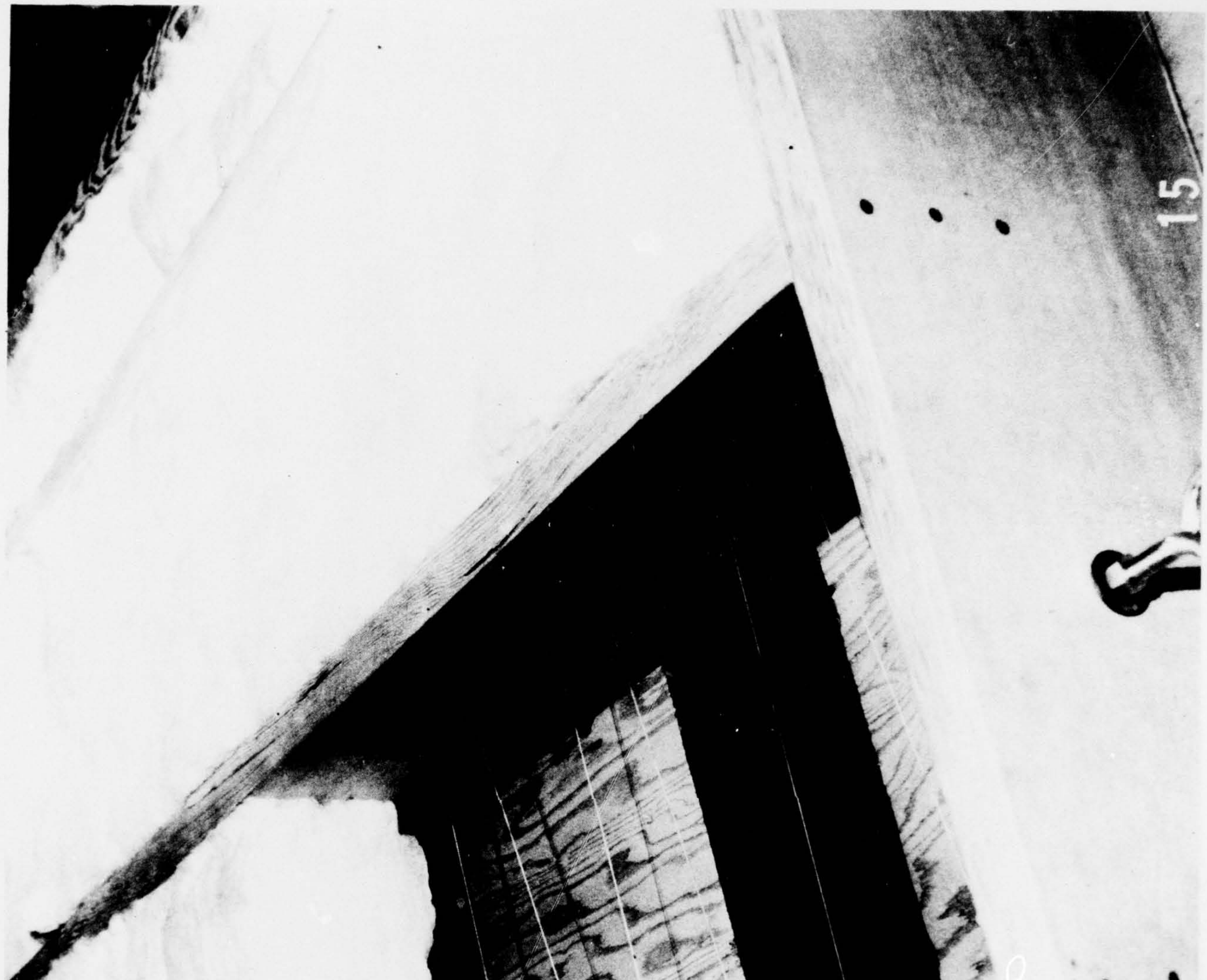
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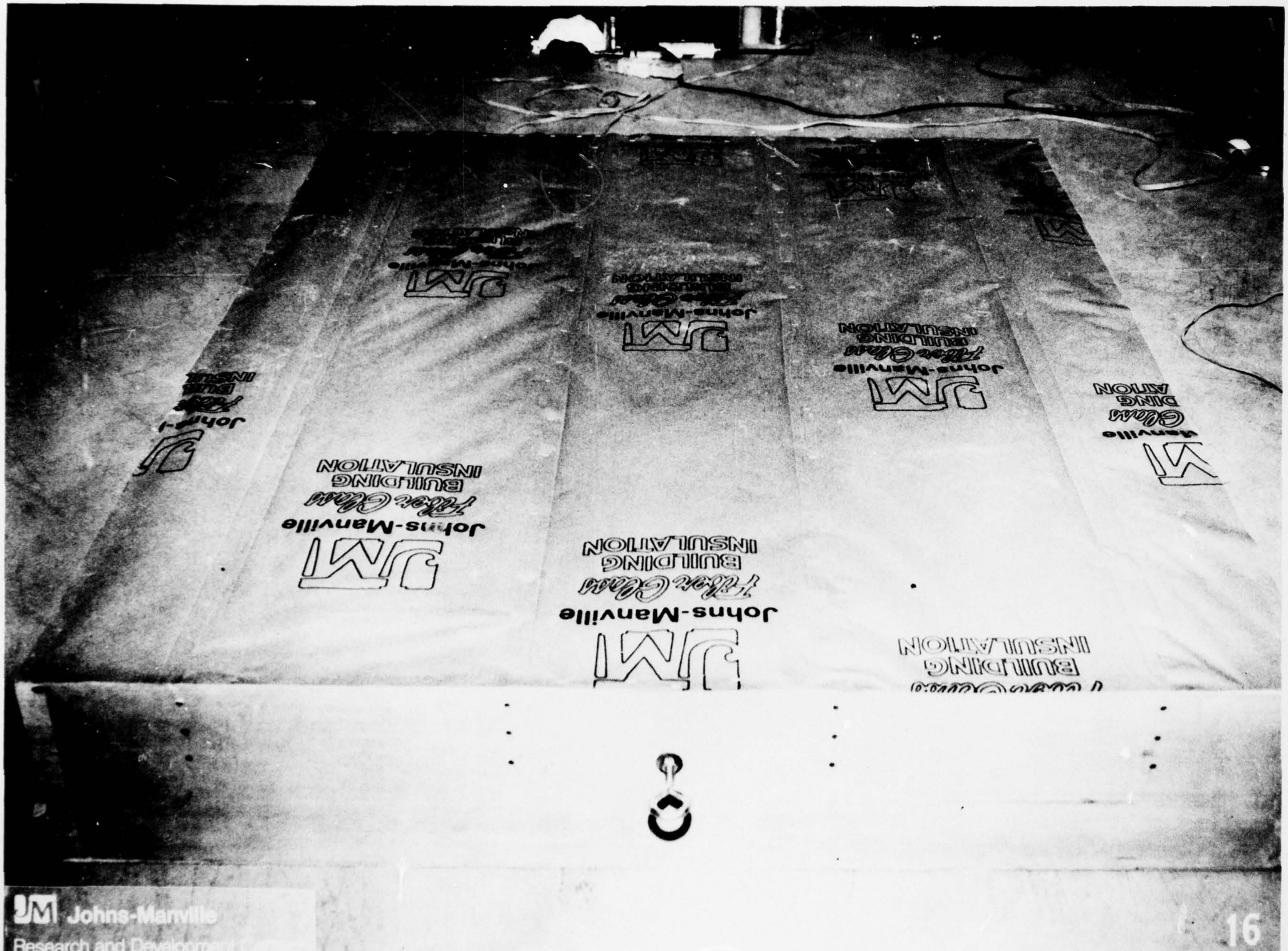
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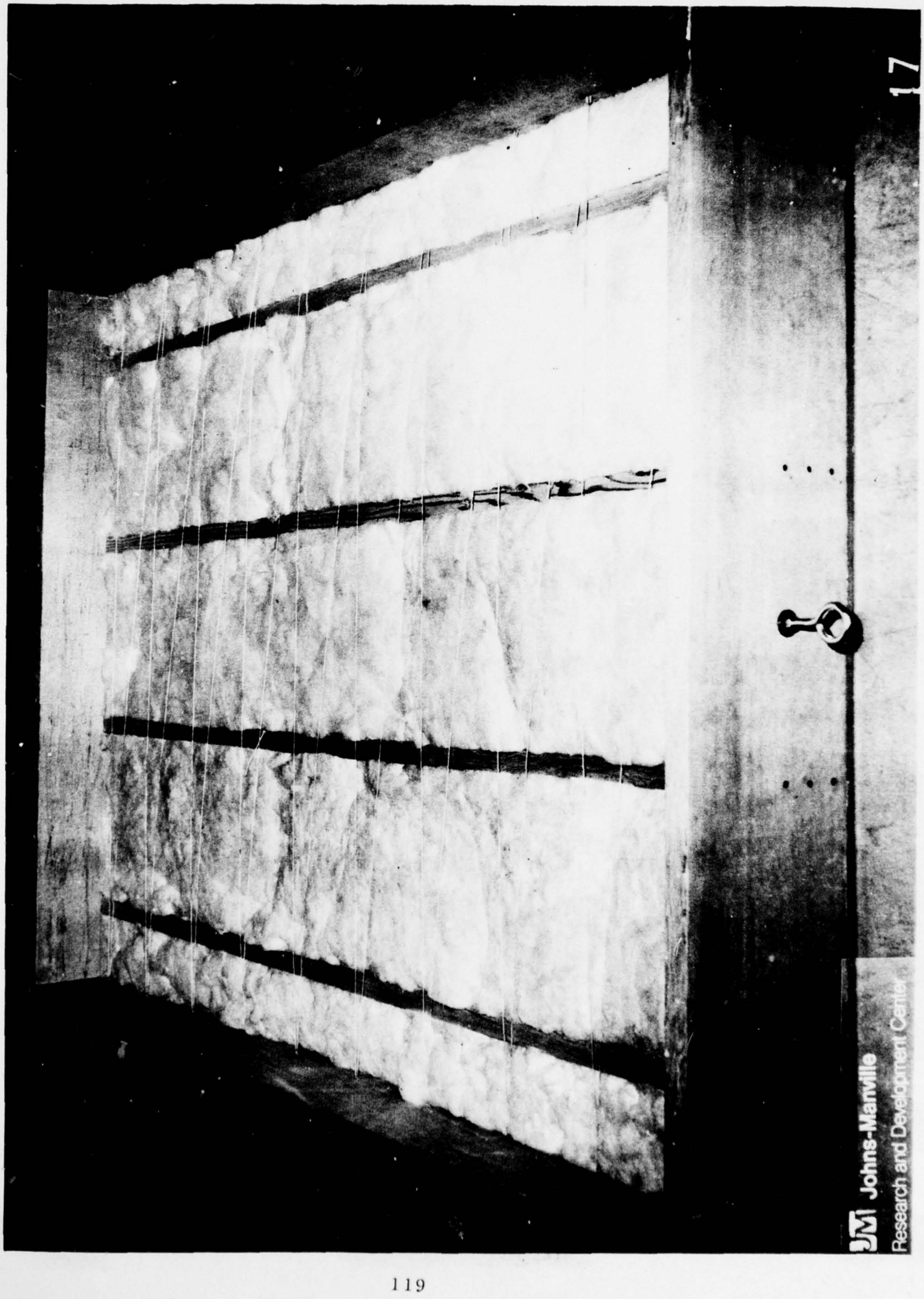
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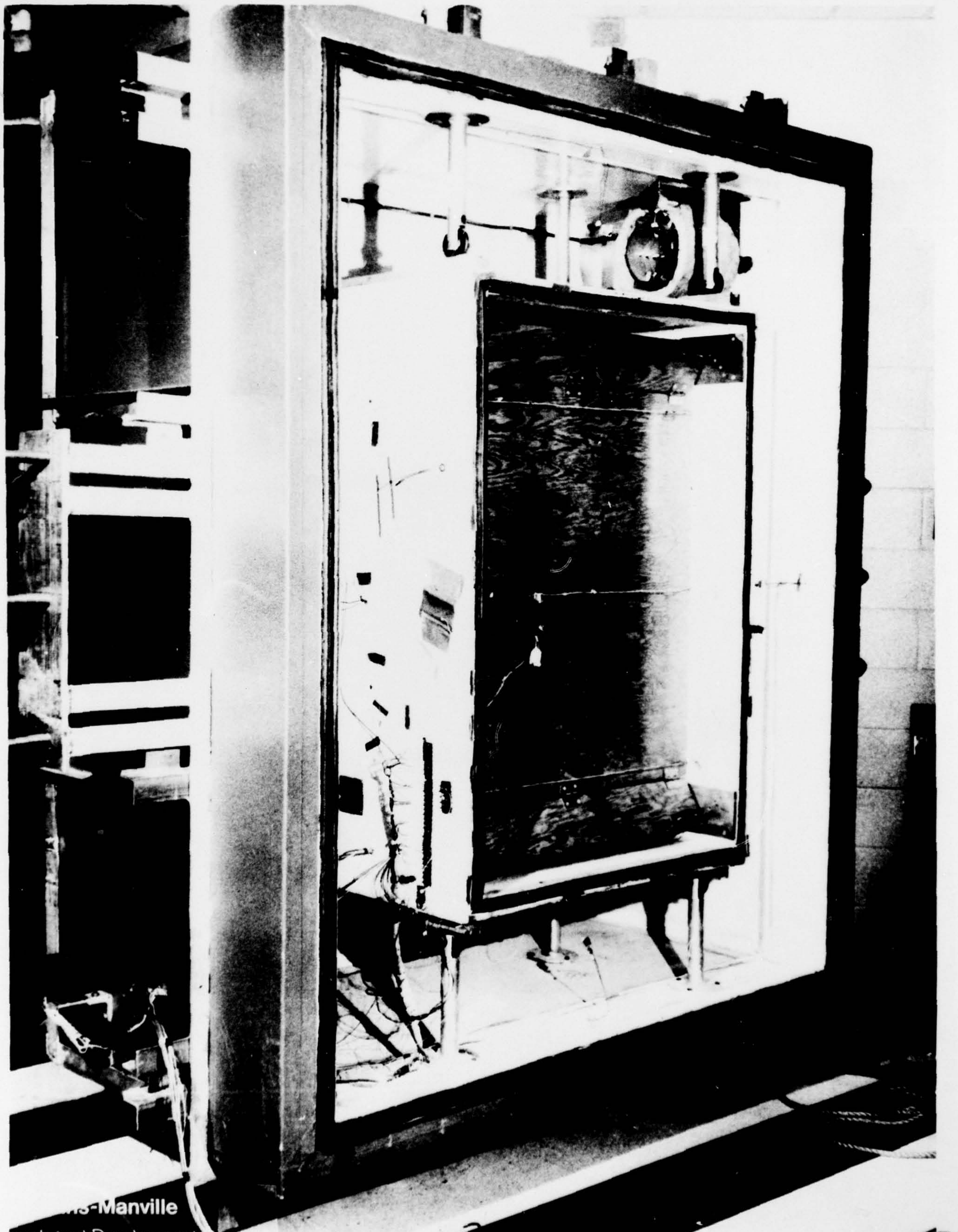
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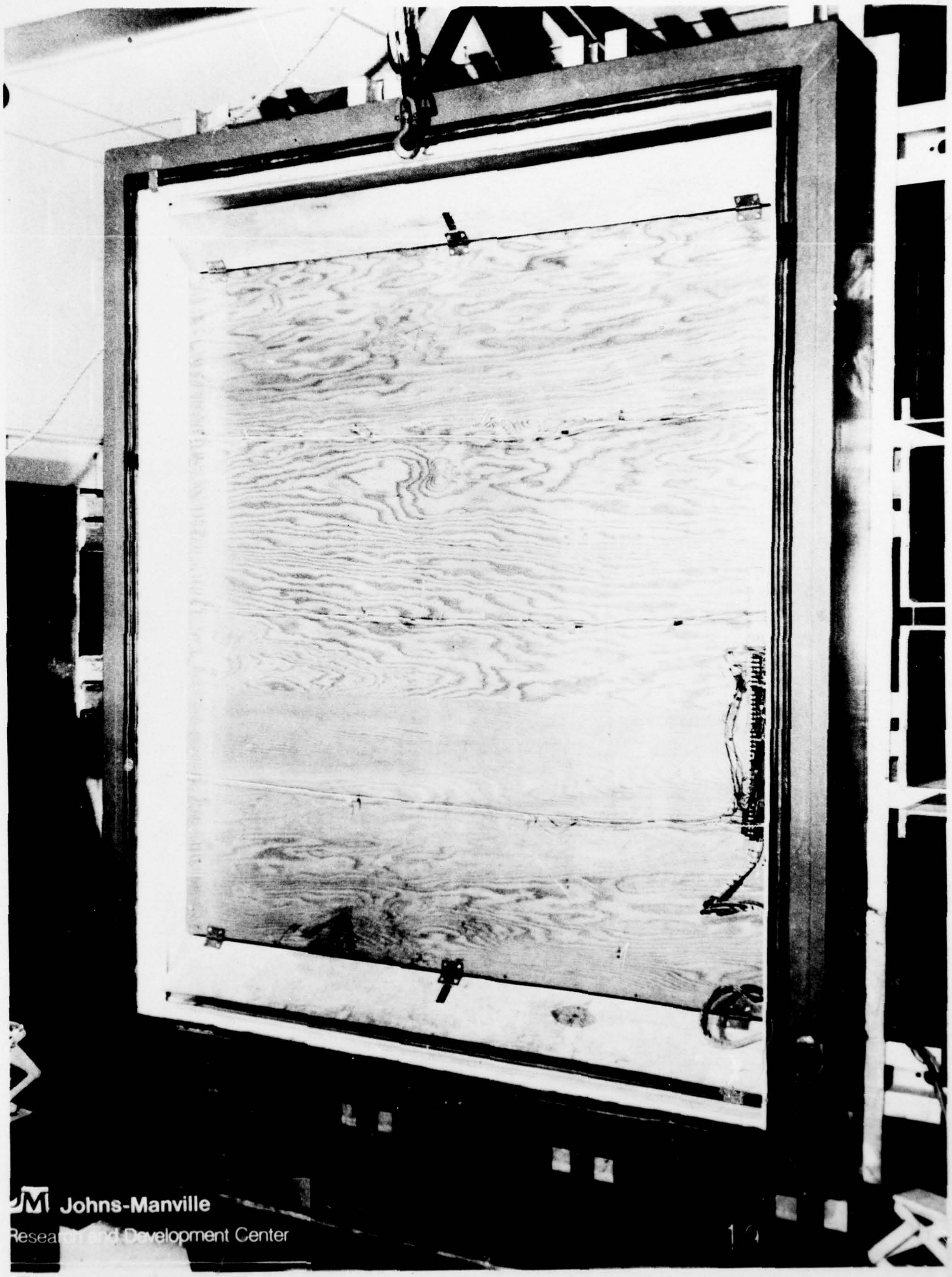
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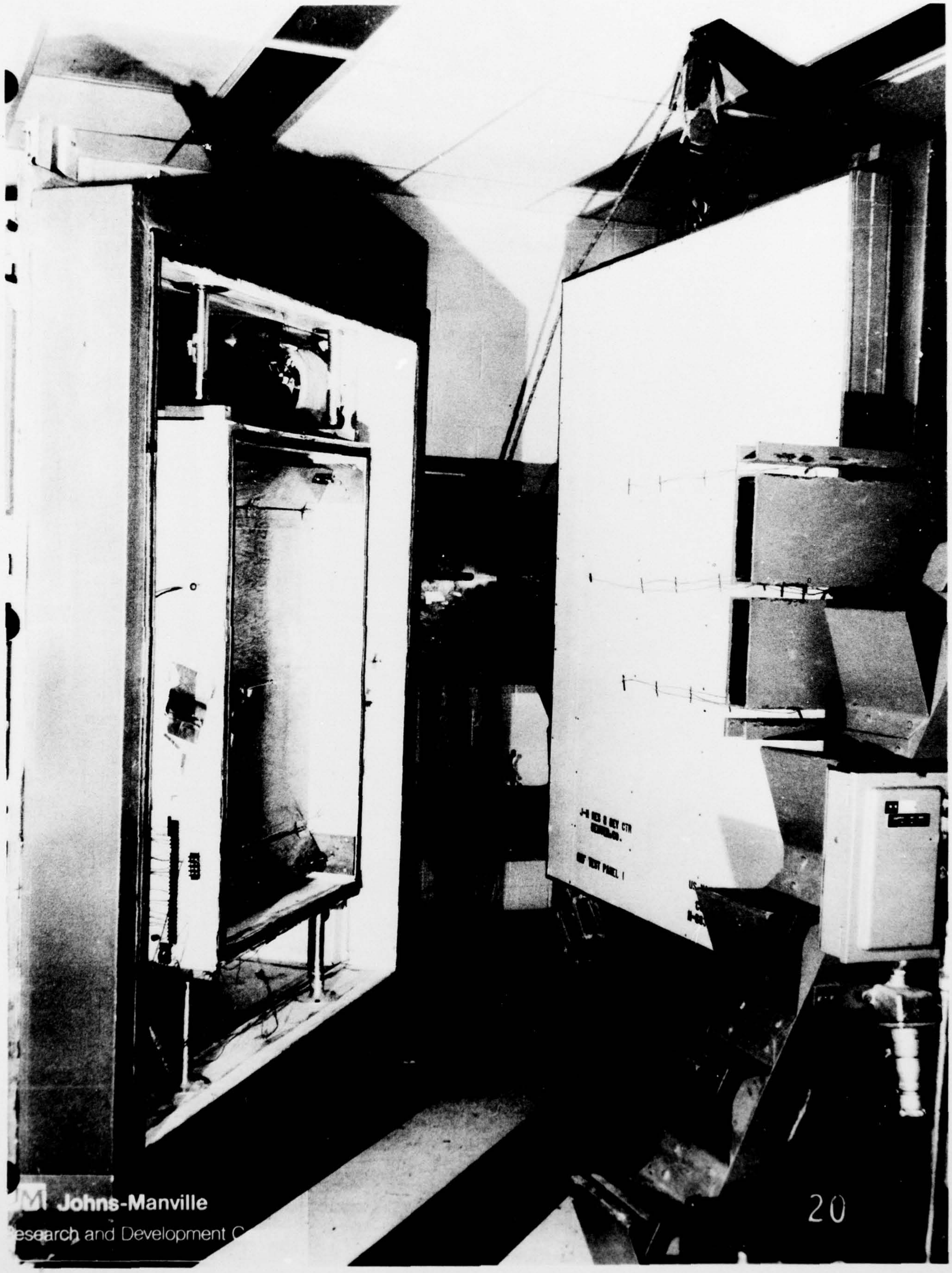
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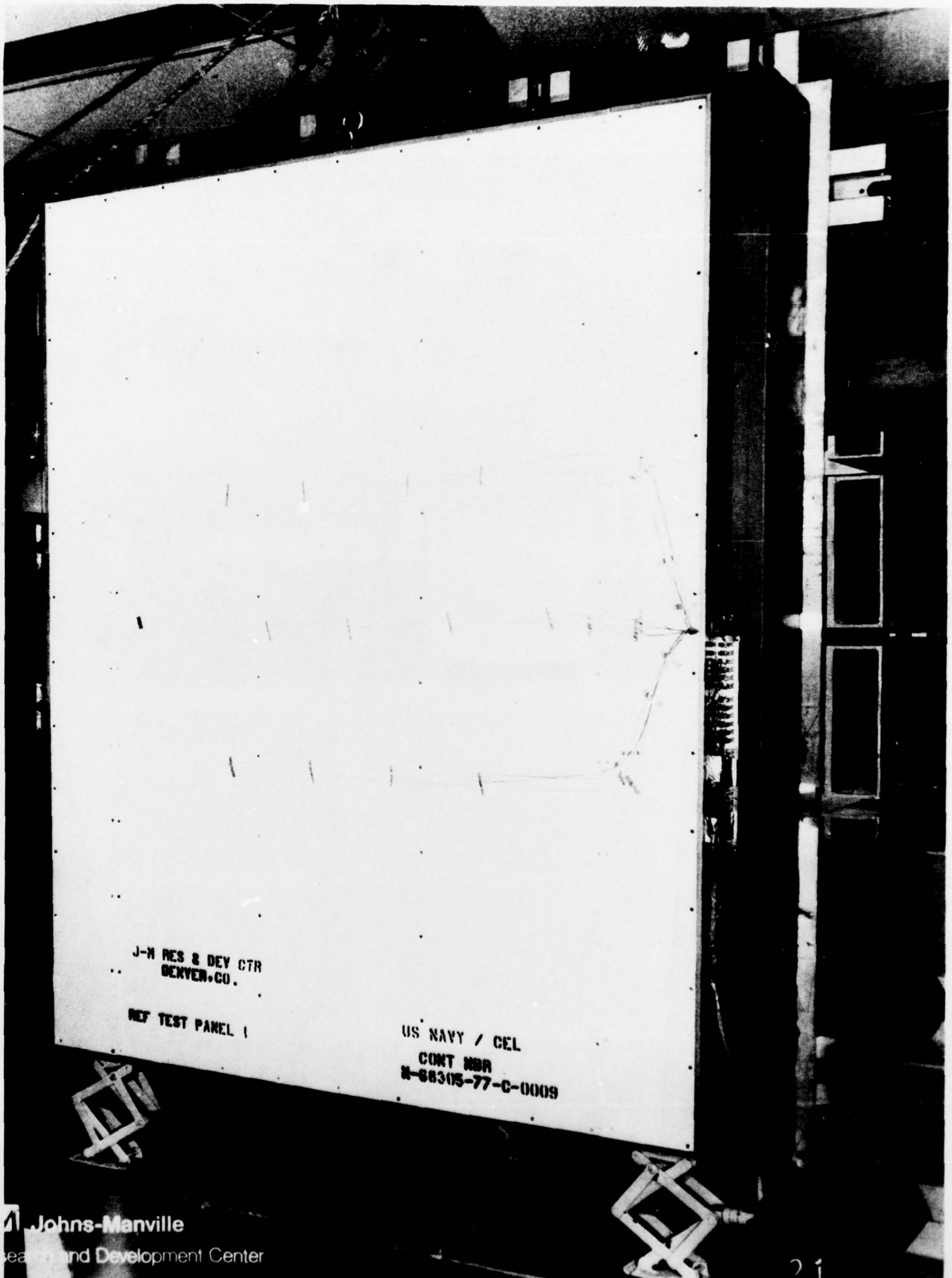
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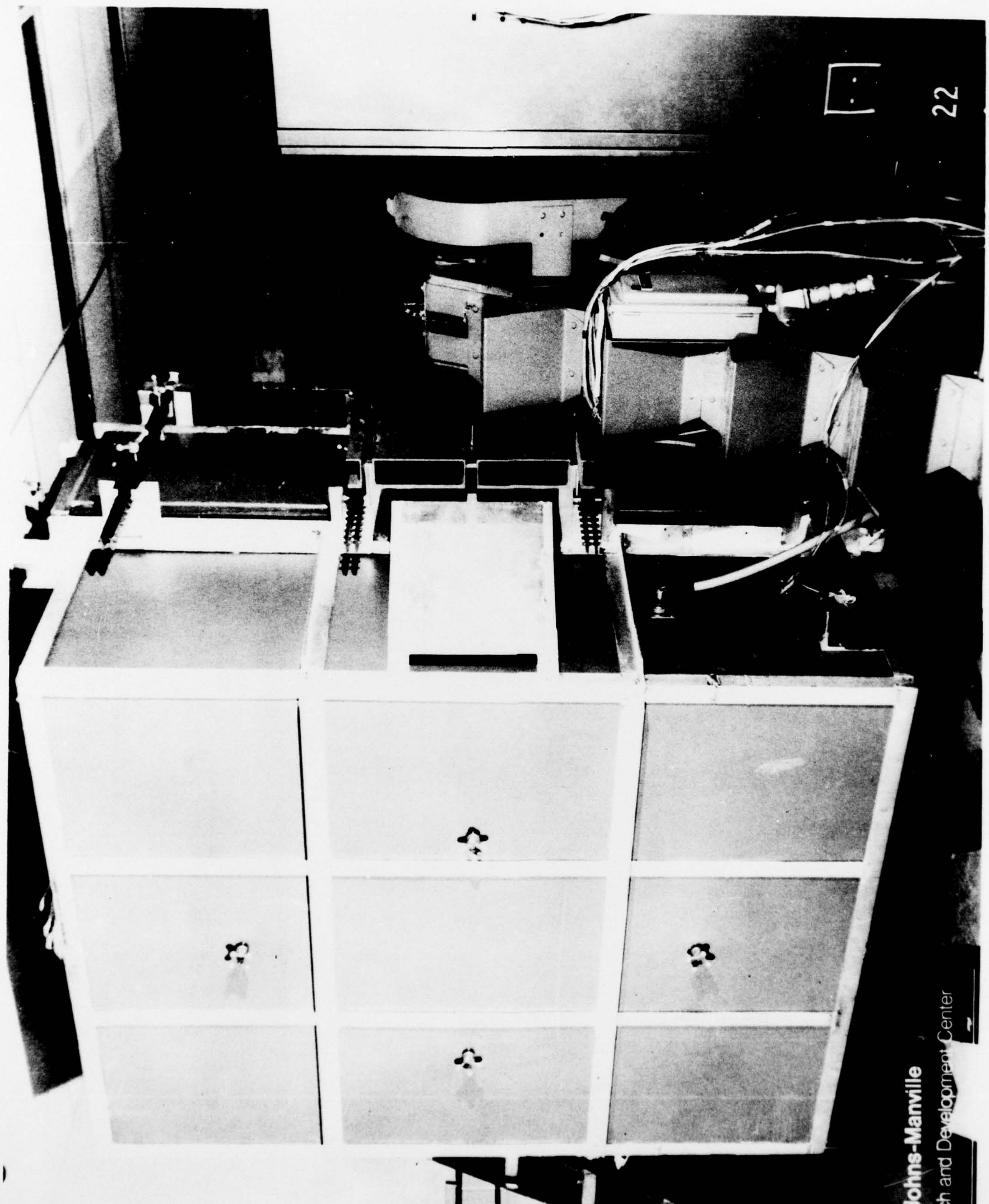
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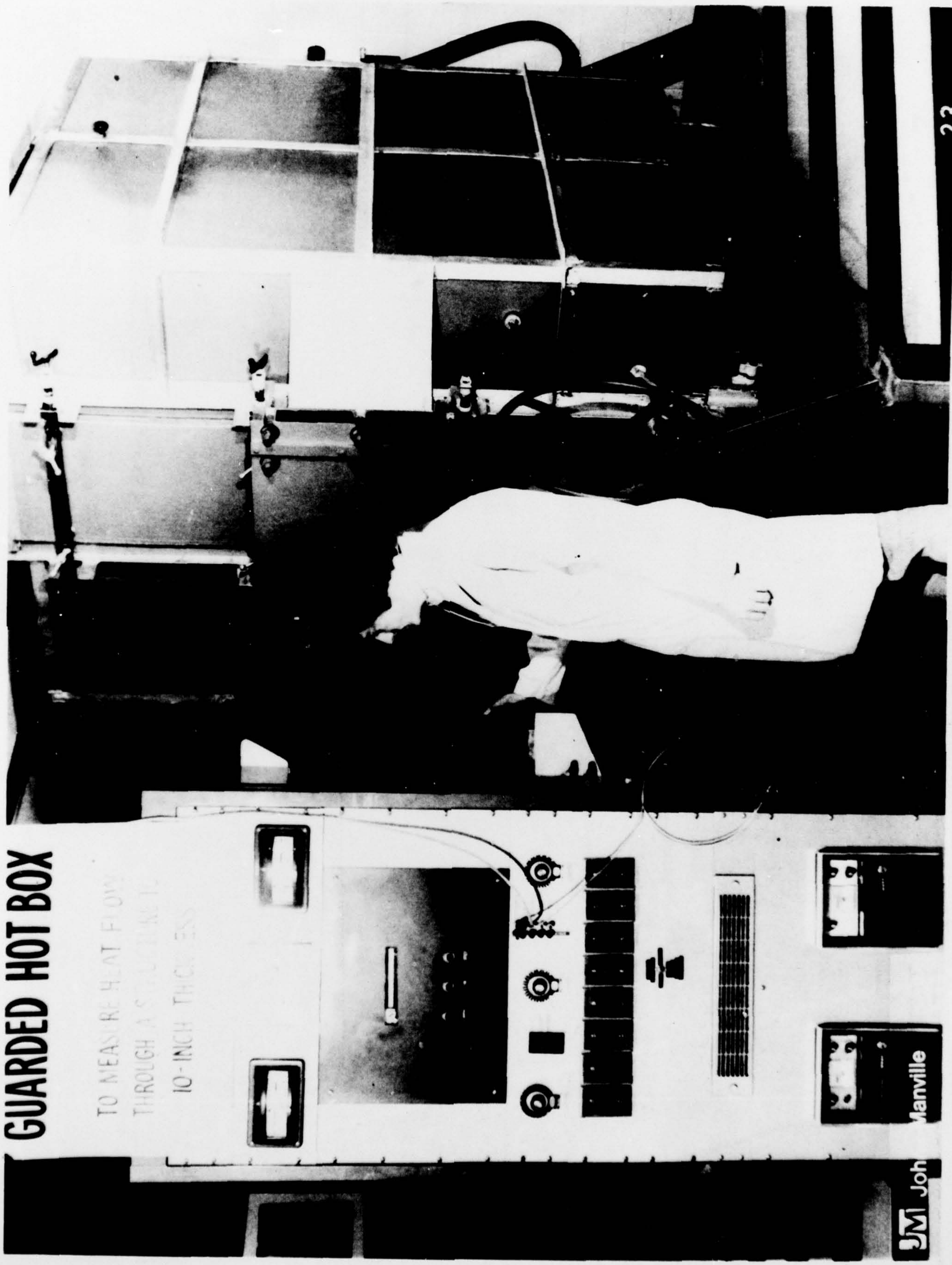
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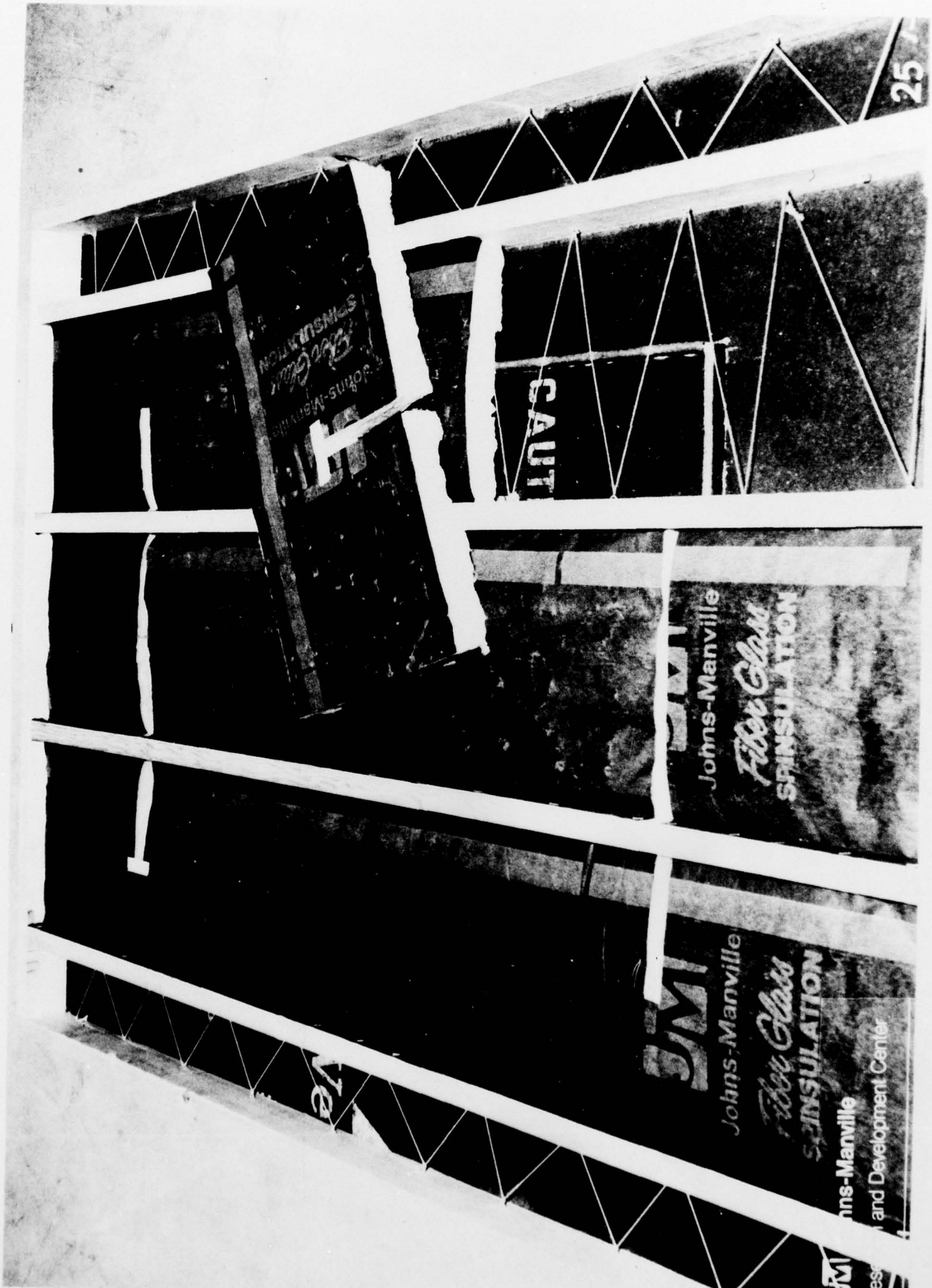
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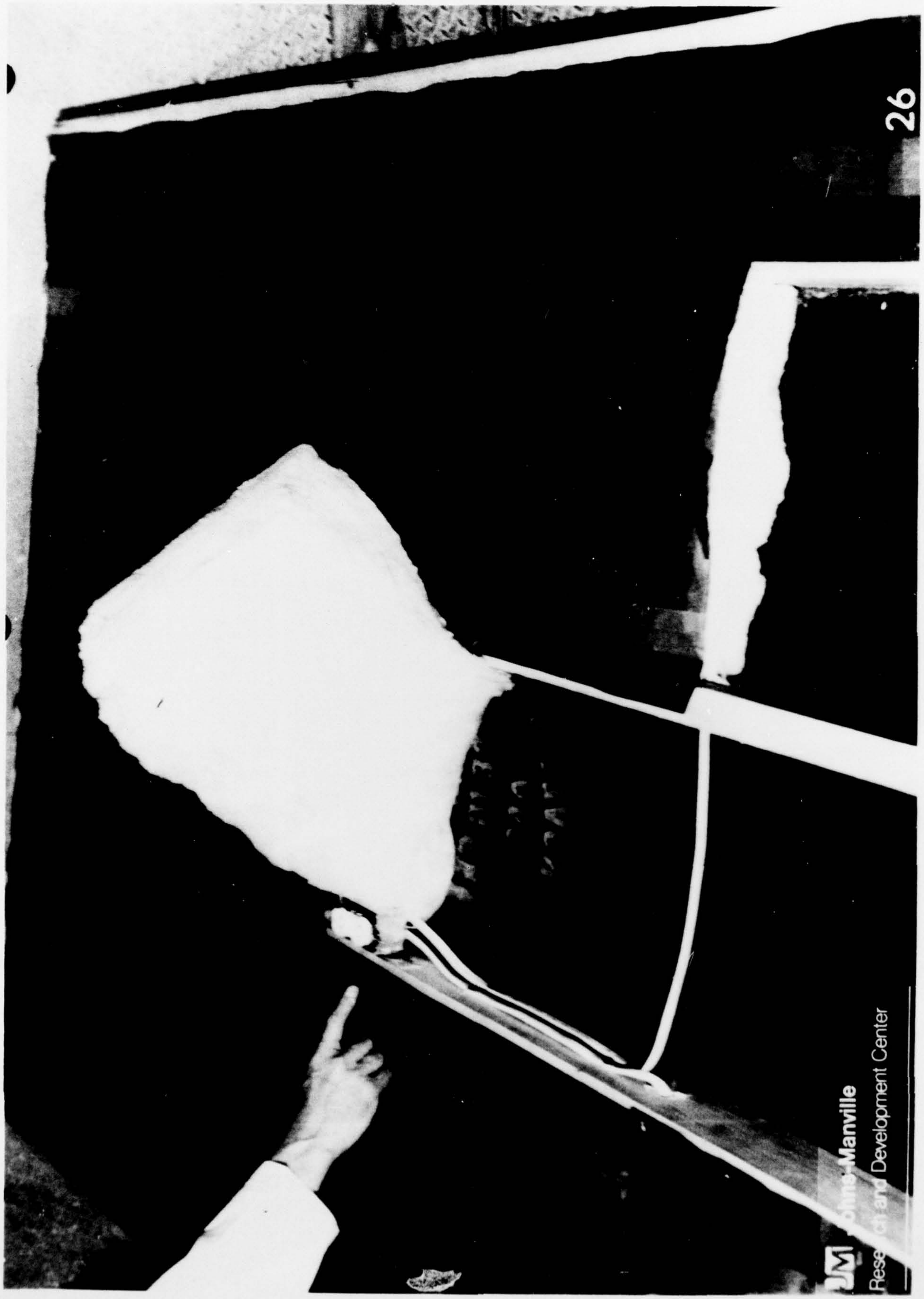
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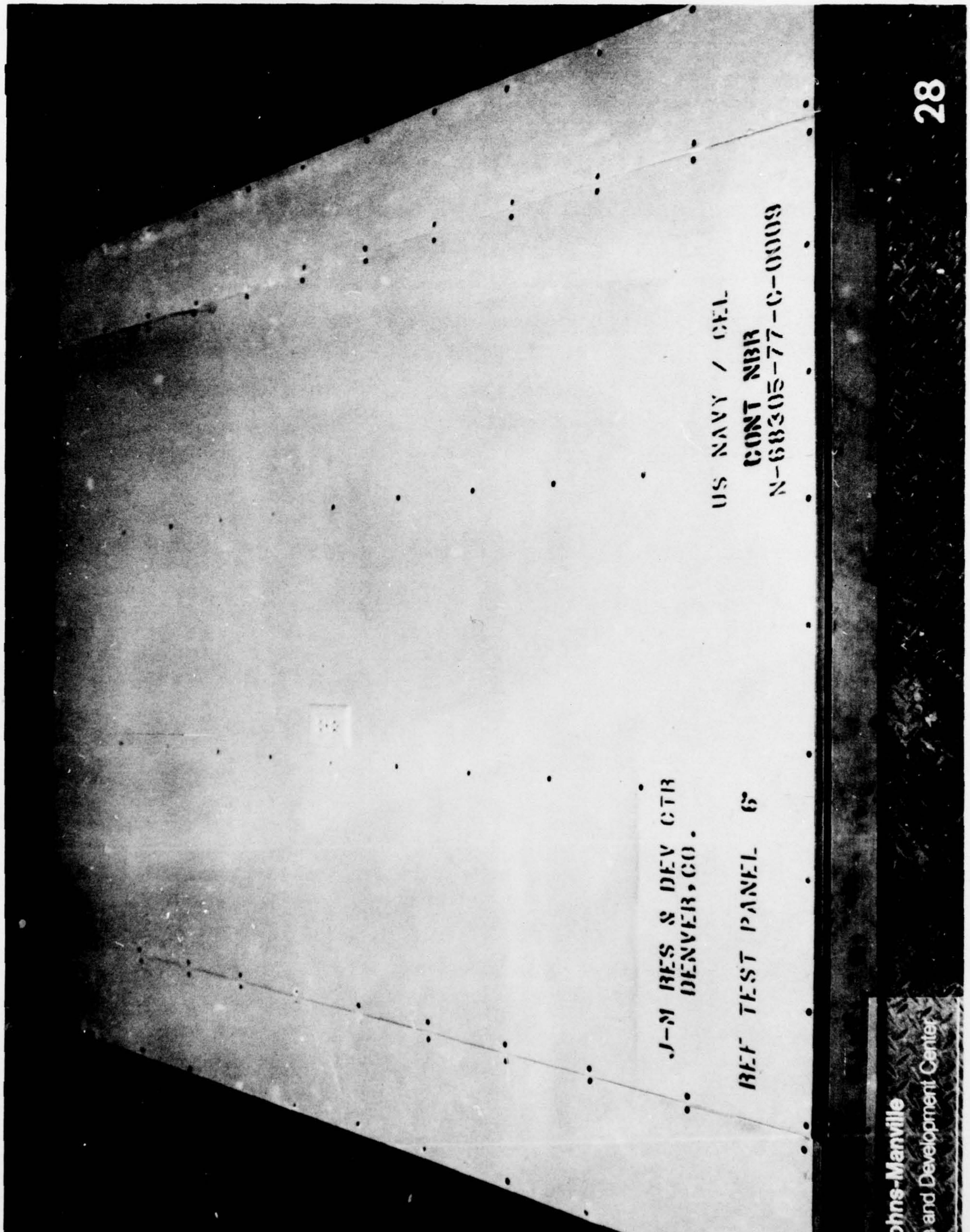
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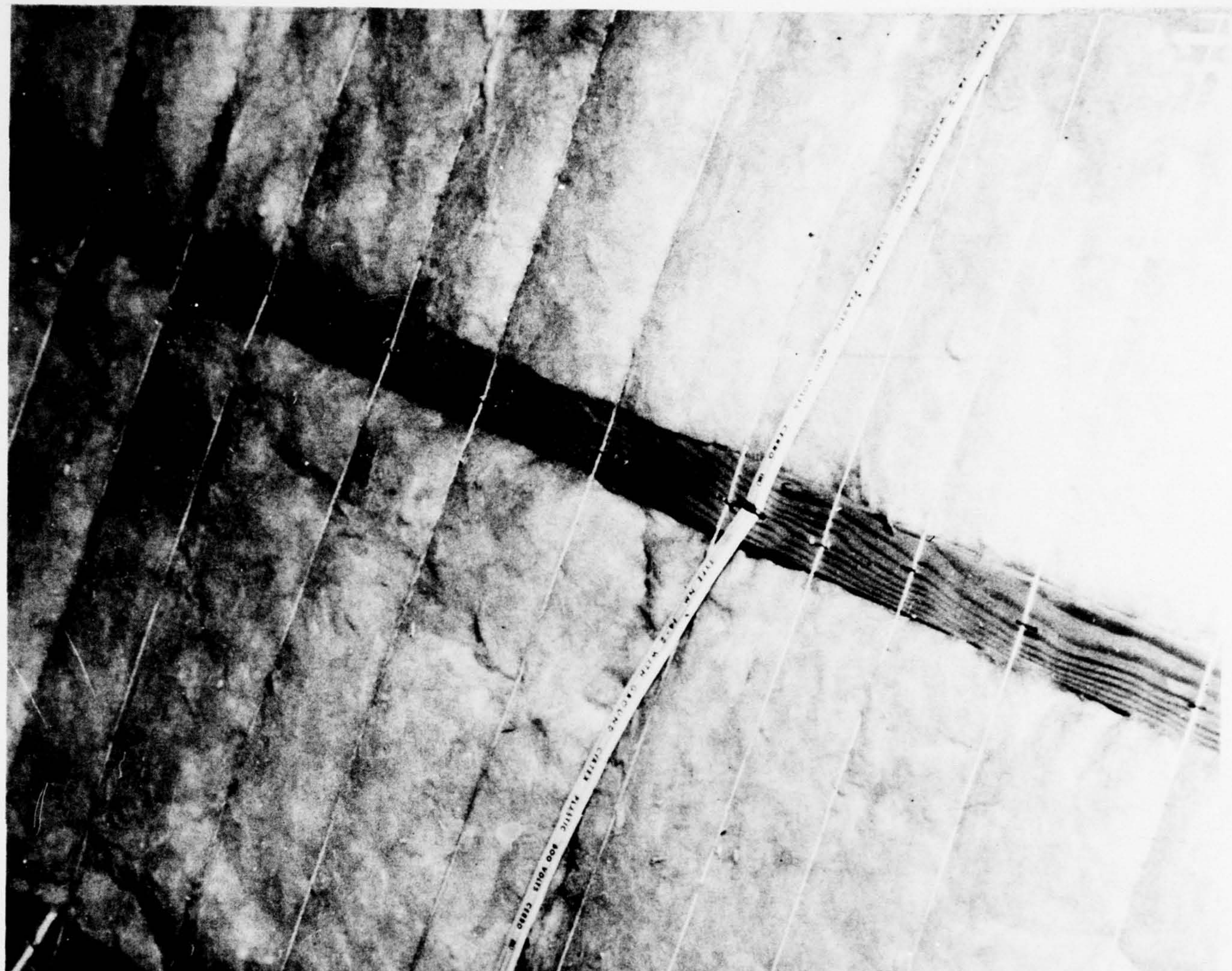

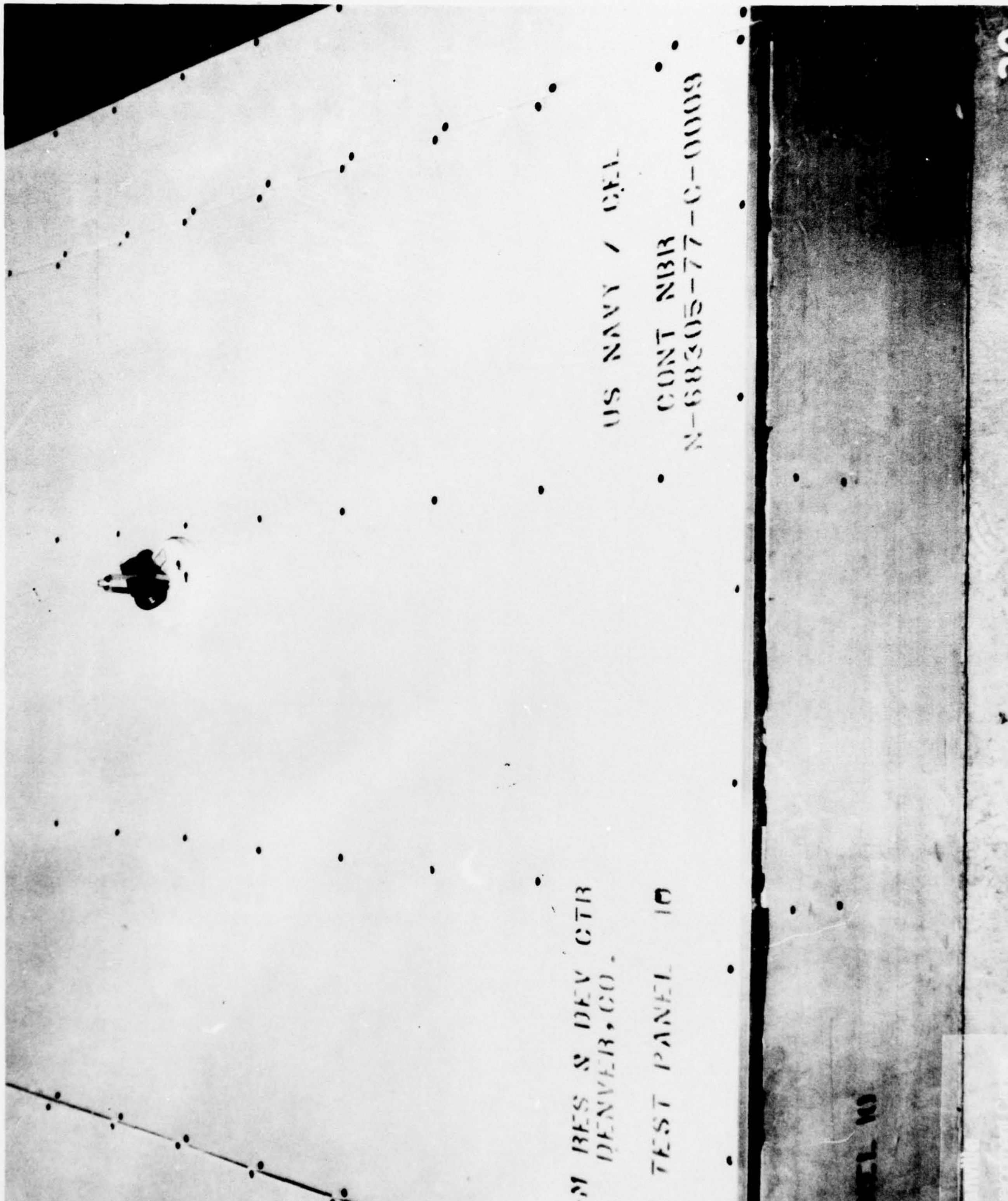
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